The determinants of decentralised photovoltaic (PV) adoption in urban Nigeria and a verified model for rapid diffusion

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Abstract

Microgeneration technologies like residential solar photovoltaic (PV) systems have been shown to have immense potential for energy security and climate change mitigation. As a way of helping to resolve the decades-long power challenge in Nigeria, this study investigated the barriers to, and motives for, domestic PV adoption in Nigeria. It also assessed whether household PV can lead to increased energy use efficiency and examined the role of Government incentives towards large-scale uptake and diffusion.

Adoption and innovation diffusion theories, willingness-to-pay (WTP), coproduction and self-help concepts were employed. Results were analysed using mainly Lagos State household data, collected through questionnaire surveys and interviews. Findings from correlation and logistic regression revealed the major barriers as high capital costs, lack of finance and low awareness. Field survey analysis established the key motives for uptake as power outages, cost-savings, including generator use fuel fraud and access to finance. It also showed that post-PV, adopting households engaged in more energy efficient practices. From this data the PV efficiency cycle was developed to demonstrate how energy conservation occurred.

Empirical evidence from the surveys, interviews and LCOE calculations were used to design a verified model for rapid PV diffusion. This decision-making tool can be used by the Government, policymakers, PV designers, SMEs and households for choosing an appropriately-sized module. The results point to the need for regulatory and political intervention. Effective PV awareness creation campaigns and promotional strategies would also be necessary in the changing face of electricity supply in Nigeria.

Dedication

For my parents, Chief & Mrs G.C.N Ugulu (JP)

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Glossary

BIPV- Building Integrated PV

BOS- Balance of Systems

BRICS-Brazil, Russia, India, China, South Africa

CA- Conjoint Analysis

CAQDAS- Computer Assisted Qualitative Data Analysis Software

CF- Capacity Factor

CIF-Climate Investment Funds

CPV- Concentrating PV

CSP- Concentrating Solar Power

CVM-Contingent Valuation Methods

DBDC-Double-Bounded Dichotomous Choice

DC-Dichotomous Choice

DCE- Discrete Choice Experiment

DECC-Department of Energy and Climate Change

DG-Decentralised Generation

DSIRE –US Database of State Incentives for Renewable Energy

DSO- Distribution Service Operators

ECEEE- European Council for an Energy Efficient Economy

ECN- Energy Commission of Nigeria

EEA- European Environment Agency

EEG- Erneuerbare-Energien-Gesetz

EPSRA- Electric Power Sector Reform Act

ESMAP-Energy Sector Management Assistance Program

EV- Electric Vehicle

FIT-Feed-in tariff

GDP- Gross Domestic Product

GEF- Global Environment Facility

GHA- Glasgow Housing Association

GHGs-Greenhouse Gases

GLM- Generalized Linear Models

GSE- Gestore Servizi Energetici

GW-Gigawatt

GWh-Gigawatt hour

IBILE-Ikeja, Badagry, Ikorodu, Lagos Island and Epe

IEA-International Energy Agency

IPP-Independent Power Producers

kWh- kilowatt hour

kWp- kilowatt peak

LCDAs- Local Council Development Areas

LCOE- Levelized Cost of Electricity

LECZ- Low Elevation Coastal Zones

LGAs- Local Government Areas

LSHA- Lagos State House of Assembly

MAED- Model for Analysis of Energy Demand

MBDC- Multi-Bounded Dichotomous Choice

MCS- Microgeneration Certification Scheme

MDG-Millennium Development Goals

MEPL-Minimal Energy Poverty Line

MGTs-Microgeneration Technologies

MINT-Mexico, Indonesia, Nigeria, Turkey

MLE- Maximum Likelihood Estimates

MVA- Missing Value Analysis

MW-Megawatt

MWh- Megawatt hour

MYTO-Multi-Year Tariff Order

NERC-Nigerian Electricity Regulation Commission

NGOs-Non-Governmental Organisations

NIPP- National Integrated Power Project

NPV-Net Present Value

OECD-Organisation for Economic Co-operation and Development

OFGEM-Office of Gas and Electricity Markets

OPV- Organic Photovoltaics

Payback Time-PBT

PHCN-Power Holding Company of Nigeria

PURPA- US Public Utilities Regulatory Policies Act

PV-Photovoltaic

PWU- Part Worth Utility

REMP- Renewable Energy Master Plan

RES-E-Renewable Energy Sources Electricity

RES-Renewable Energy Sources

RETs-Renewable Energy Technologies

RHI- Renewable Heat Incentive

ROC- Renewables Obligation Certificates

ROI- Return on Investment

RP- Revealed Preference

RPS-Renewable Portfolio Standards

SBDC-Single-Bounded Dichotomous Choice

SD-Sustainable Development

SED- Senior Experts Dialogue

SHS- Solar Home Systems

SI- Systems Innovation

SMEs-Small and Medium-scale Enterprises

SPSS-Statistical Package for the Social Sciences

SP-Stated Preference

STEER- Socio-cultural, Technological, Economic, Environmental and Regulatory

T&D- Transmissions and Distribution

TGCs-Tradable Green Certificates

UNECA-United Nations Economic Commission for Africa

WOM-Word-of-mouth

Wp-Watt peak

WTP-Willingness-to-pay

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Chapter 1

1.1 Introduction

Nigerian households are '*experienced*' conventional self-generators. Traditionally, households demanded more electricity than they supplied but in recent years the reverse has been the case (Sambo, 2008). Decades of unstable national grid electricity supply has meant that most households in Nigeria use petrol and diesel-operated generators as back-up power. However, the latest changes to the Multi-Year Tariff Order (MYTO) resulting in an increase in electricity tariffs (Financial Times (FT), 2012) and the gradual phase-out of fuel subsidies (BBC News, 2012) have led households and other private power consumers seeking better power supply alternatives.

The MYTO policy passed in 2011 was designed to make electricity prices reflect its true costs (ESMAP, 2013). Many years of subsidising electricity tariffs and petroleum products costs has meant that the rates sold to consumers were set below the marginal cost of production (Nigerian Electricity Regulation Commission (NERC), 2013). The problem with direct market distortions such as fossil fuel subsidy, is that it becomes difficult, if not impossible, for the government to recover the cost of investment. Meanwhile, the fixed costs of investment remain. This goes on to affect the funding of other equally vital public infrastructures e.g. the health and education sector.

There are other downsides to using subsidies to support conventional electricity and energy supply as a whole over a long term. The obvious ones are wastefulness and poor service. Recent evidence has proven that the impact of fossil fuel subsidies on the Nigerian economy was more detrimental than helpful (Siddig et al, 2014). When people are made to pay less than a product or service actually costs without any way of fully recovering the investment capital, it means that the services may not be delivered optimally as the supplier struggles to make ends meet in terms of reinvestment and labour payments.

In consequence, mains electricity supply in Nigeria has been largely intermittent and unreliable for many decades. Though subsidies are designed to assist the poorer masses in society (Solaymani and Kari, 2014), they also benefit the well-off whom they are not intended for. Thus, subsidies on fossil fuels are meant to be strategically used and on a short term basis as they hinder energy efficiency measures (Sovacool, 2009).

1.2 Background of the Study

Reliable electricity supply is vital for economic growth and social development. Regular electricity supply, renewable power supply and energy use efficiency is a constant theme of the United Nations Millennium Development Goals (MDGs) (UNEP, 2014). The reason for this continued emphasis on better and improved energy use patterns is that the key to poverty reduction and achieving a more sustainable economic development lies therein (Stern, 2007).

The heavy reliance on conventional energy sources is being discouraged for two main reasons. Firstly, fossil fuel use creates negative externalities or market shocks as the environmental damage from fossil fuel consumption is unaccounted for in its pricing (Sovacool, 2009). This is where Decentralised Generation systems (DGs) such as solar photovoltaic (PV) systems become useful as they negate the impact of demand shocks. Fossil fuel combustion remains a risk to the earth's ecosystems due to Carbon Dioxide (CO_2) emissions, which is a strong contributor to rising greenhouse gases (GHGs) (Stern, 2007). Hence, reducing the use of fossil fuels will help mitigate the threats posed by climate change.

Secondly, the rising prices of energy products amidst conflicts in oil producing countries also pose a threat to the security of vital energy systems (Asif and Muneer, 2007). To better manage the effects of fluctuations in energy prices, huge investments in Renewable Energy Technologies (RETs) are required (Neuhoff, 2005). Unlike fossil fuels, PV usage makes countries more independent resulting in energy autarky (Peacock et al, 2014) as well as creating positive externalities. Many countries across the globe have recognised this and started making the necessary changes to their existing energy portfolio by including a good mix of RETs. But the uptake of residential PV and other RETs in Nigeria has been slow. A study revealed that countries which support and adopt PV earlier than their counterparts, before they even become cost-competitive, stand to benefit (Neuhoff, 2005).

1.3 Rationale of study

The rationale for this study can be broadly categorised into social, economic and environmental rationales. These are discussed in sequence below.

Social factors

The quality of life of a people can be significantly improved by reliable electricity. Household wellbeing is the key to engaging in any form of trade or business activity. Ill-health which can arise as a result of using primary fuels for cooking and lighting can negatively impact the ability of individuals to contribute meaningfully to the welfare of their family and society at large. With uninterrupted power, families can spend more time together and visit friends without fear of going out when it gets dark. This encourages interaction and fosters socialising which also improves the health and wellbeing of individuals.

With the advent of social media and the rise in the use of smart phones and modern electrical gadgets, people are now more inclined to engage on wide-ranging socio-economic and political issues. Using these mobile platforms require that the devices can be easily charged when the batteries run out. The lack of stable power in Nigeria has created a new trend where consumers have to constantly search for a charging point for their mobile phones and tablets to be recharged. While this has created a kind of business for a few people, it is not the sort of business that can grow a civilised society as much of the proceeds go into the informal sector.

Economic factors

The economic benefits arising from regular electricity and energy use are widely acknowledged. Energy is the power to do work and is the basis for the economic growth of any society (Tippens, 2001). It has even been compared to other factors of production such as land, capital and labour (Ikeme and Ebohon, 2005) due to its strong links to human progress and economic advancement. Of the energy sources electricity is the most important as it underpins every other source of energy used in modern day. It is stated that no country will develop beyond a subsistence living without ensuring at least the minimum or basic electrical energy access needed for its population (Steer et al, 2000). This is because energy in the form of electricity is central to the cultivation of food, clean water supply, housing, healthcare, education, job creation and for effectively maintaining national security.

Where the requisite reliable electricity is missing the economy suffer in various forms. Children are unable to learn after dark. When they do using substitutes such as candles, they are left vulnerable to danger. Candles and kerosene lamps pose fire risk and can be damaging to the health and safety of the user due to the fumes emitted during its use.

Parents cannot engage fully in extracurricular activities with their wards. Children cannot reach their full potential under such circumstances, as they are left to teaching and learning that takes place only within the confines of the school. The result is poor quality education which goes on to affect employment opportunities, human development, economy and total life chances.

The absence of power significantly affects firms' ability to properly function as no modern business can effectively operate without power. Iwayemi (2008) showed how unreliable power can hinder competitiveness of industries both locally and internationally. Unstable grid networks increase the costs of doing business which are then passed on to consumers. Some businesses that are not so fortunate would be priced out of market by dominant businesses with more capital. Ikeme and Ebohon (2005) recounted how some firms have folded up as a result of their inability to sustain their business using private generation, which can be much more expensive than mains electricity. An unconducive business environment hugely undermines economic growth and impacts employment. Small and big businesses that are unable to meet the demands of their clients lose out to stronger more prepared competitors. Hence, regular power supply does not only create job opportunities, it also sustains them.

In addition, heads of families can now work for longer after office closing hours if need be. In the era of home working, individuals can engage in economically beneficial activities irrespective of the time of day. Business owners can respond to the requests of their customers promptly, including those of clients based abroad. At the end of the month they declare their profits and losses to the Inland Revenue and pay their taxes. Such contributions, no matter how small, bring about economic growth and prosperity over the long term. In general, PV has the power to create employment, especially for the local workforce, as exemplified by Germany which employs over 85,000 people in its PV industry. China has created more than 300,000 PV jobs mainly in manufacturing. The European PV employment figures later fell due to the withdrawal of support incentives (IEA, 2014).

Environmental factors

Nigeria remains one of the most vulnerable locations prone to global warming (CIF, 2010). In the event of a catastrophe, Nigeria as with most developing countries, will be less able to deal with the consequences of climate change (Gujba et al, 2012). The use of trees for fuel wood constitutes a legacy of degradation as trees serve as a sink and help to absorb CO_2 (Asif and Muneer, 2007). Fuel wood and kerosene use for cooking can be dangerous as smoke and fumes are inhaled by the users. They also pollute the environment. These traditional energy sources are environmentally destructive and their continued use would inadvertently result in a degraded environment with economic and social implications. Also, the unquantifiable negative externalities will result in more cost burden for the government, as people become ill from air pollution and environmental damage.

Over reliance on fossil fuels can also create significant environmental damage. Some urban centres in Nigeria including Lagos state have been shown to fall under the United Nations (UN) Low Elevation Coastal Zones (LECZ) (UN Habitat, 2008; Climate Investment Fund, 2013). Natural disasters in these low-lying zones would severely affect the entire economy with the most vulnerable greatly affected. There is also the issue of deforestation, erosion and desertification, which stems from wood felling for fuel wood in many rural locations.

The Nigerian government in desperation to provide adequate electricity for the entire population appear to be showing preference for fossil fuel based electricity because it is considered cheaper than RETs (Gujba et al, 2011). Inclination towards carbon-based power supply is not peculiar to Nigeria. At a time when the UN Paris Climate Change Conference (COP21) was finalised in favour of keeping global warming below 2^oC, close to 2,500 new coal-fired power plants are being planned globally (The Times Newspaper, 2015). This is because coal appears ‘cheap’. While this may be true in the short term, in the longer term pursuing an economic development path based largely on fossil fuel combustion will lead to increased CO_2 emissions. The above stated number of planned coal-fired plants will emit 6.5 billion tonnes of CO_2 per year (The Times Newspaper, 2015). Switching to green power sources now can subvert the trail of past poor energy choices and rebalance the Nigerian economy towards a low carbon society.

1.4 Aims, hypothesis and objectives

1.4.1 Research aims/hypothesis

This study is broadly aimed at providing the mechanisms to assist with the improvement of electricity generation legacy in Nigeria. Having established the household sector as an important one in energy demand in Nigeria, this study aims to promote household level PV use for electricity generation in urban areas. The research will focus on the determinants of PV adoption and the effects of government policies on PV diffusion in an effort to determine whether favourable government policies can increase the take up of PV systems by the private sector in Nigeria. Noting that energy efficiency measures like PV installation sometimes leads to a rebound effect[1], it questions whether off-grid solar PV can result in energy demand reduction and use efficiency.

1.4.2 Research questions/Hypothesis

i) The constraints to PV deployment by the urban residential sector can be removed by appropriate support policies

ii) Urban residential-scale PV adoption would promote domestic energy use (DEC) efficiency

1.4.3 Specific objectives and scope of study

Through a desk-based study in the UK and field trip to Nigeria the objectives of this research are:

- To undertake an independent investigation as to the barriers to and motives for household-level PV use.
- To identify the likelihood of Government support i.e. feed-in tariffs (FITs) and net metering accelerating PV uptake.
- To establish whether household PV uptake could lead to energy use efficiency.
- To gain insight into the factors necessary for a successful implementation of PV policies.
- To provide a knowledge-based evaluation of PV policy options in order to give the Nigerian government confidence to support private sector investments in PV.
- To design a verified model for PV uptake so as to assist government with promoting urban residential PV for low, medium and high income households.

1.5 Further justification for the research

This research adopts a grassroots approach and explores the role PV can play towards improving power generation and consumption in Nigeria. To meaningfully improve residential power supply would require an alteration in demand through end-user behavioural changes. Likewise, to successfully alter demand will require a change in supply sources. This is because energy efficiency is green power's twin pillar (REN21, 2015). In order words, energy use efficiency will begin to take full effect only when

[1] Under a rebound, improved technical efficiency and falling prices lead to increased consumption; thus, offsetting the reduction in energy consumption earlier experienced (Buchanan, et al, 2015).

systems and policies addressing the supply end and the demand-side of energy use in dwellings are put in place.

Resource availability

The obvious first condition to adopt in the choice of renewables in any location is resource availability. Solar radiation resource is admirably zero-priced. But the PV device and installation has to be paid for. In the case of leased systems or Part Worth Utility (PWU), the users have to pay for the service for the duration of agreement (Shih and Chou, 2011). As a tropical country, Nigeria has a generous solar resource potential (Bugaje, 2006). The solar radiation is spread all over the country and daily average sunshine duration is about 6 hours but the areas with the highest intensities are the far northern states (Fadare, 2009). The annual average solar radiation across the country ranges between 3.5-7.0kWh/m^2day (Sambo, 2008; Fadare, 2009). This rich resource base is ideal for decentralised PV applications and would augment grid supply as countless study have repeatedly shown (Fagbenle et al, 2003; Ajao et al, 2009; ESMAP, 2013). In addition, the over exploited natural resources have been in decline with reports that they will be technically infeasible to exploit beyond 2050 (Unachukwu, 2011; Shaaban and Petinrin, 2014).

Costs and efficiency

Unprecedented time and money has been spent on revitalising the electricity sector using conventional power sources. The solutions provided have not mitigated the widespread urban power problems. Some even think that no matter the amount spent by PHCN to transform the grid infrastructure it would fail unless private sector participation is sought (Adenikinju, 2003, p. 1519). Also at the household end, in addition to hazardous fumes, private generator purchase and use can be very expensive.

It is further estimated that it would cost billions of dollars to expand the grid infrastructure (Sambo, 2009). Part of the reason is the large land area (924, 000 km^2) of Nigeria and its geographically dispersed terrain, making grid extension to rural areas extremely difficult and costly. The difficulty arises from long distances to the grid network, sometimes over 50km away (Bugaje, 1999). Grid extension to such locations would increase the transmission and distribution (T & D) losses significantly. Solar PV can be mounted at point of use thereby eliminating these losses.

Environment

In addition to costs, the inefficient conversion and utilisation of carbon intensive technologies especially in power generation, transport and the building sector is a major cause of CO_2 emissions (Neuhoff, 2005). Utilising PV and other RETs can result in more sustainable economic growth and development. Essentially, Sustainable Development (SD) implies a development path that does not deplete natural reserves and harm the environment, such as the case with conventional fossil fuels. Thus, efficient use of energy resources is a constant theme in SD programmes.

Energy efficiency is a very important element of energy policy. Sustainable use of resources reduces energy consumption and energy demand per capita, and thus offsets the growth in energy supply. Consequently, it reduces the rise in energy costs and can lessen the need for new power plants and energy imports. Moreover, the reduced energy demand can provide added flexibility in choosing the most preferred methods of energy production (Rosen, 2008).

Studies have shown that significant opportunities exist in using energy more efficiently (Golove and Eto, 1996). Efficiency in this context implies providing the same energy service at lower total costs. Decentralised PV has huge prospects in this regard. Environmental benefits accruing from using PV and other RETs have been widely documented (Stern, 2007; Rundle-Thiele et al, 2008; Ohunakin et al, 2014). If this is true, then it makes sense for Nigeria to only favour policies that help to advance novel power systems, by realising that grassroots or individual participation would be necessary to accomplish the needed power sector transformation.

1.6 General approach

The following diagram is a summary illustrating the general research processes, methodology and frameworks applied in this research.

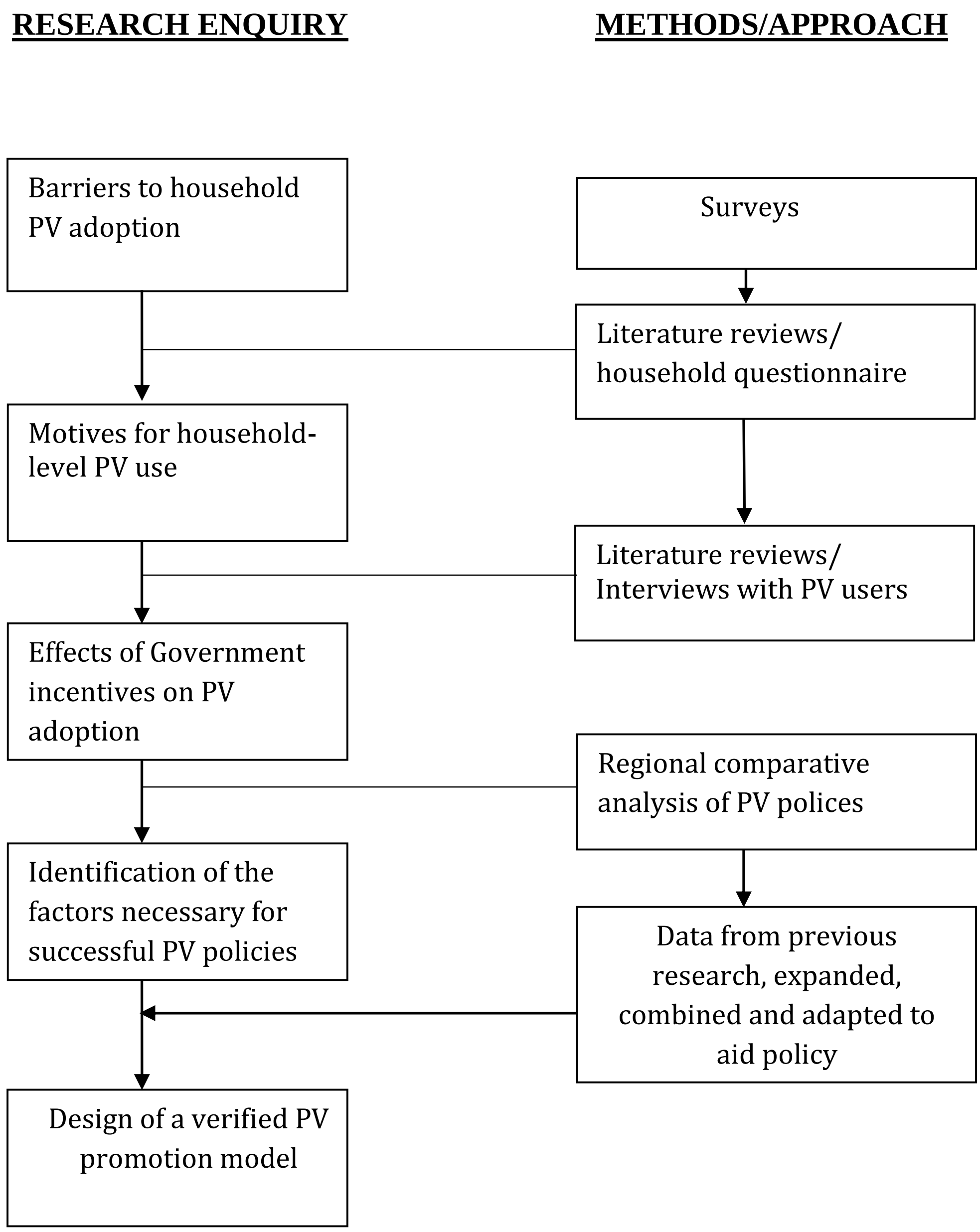

Figure 1.1 Summary of the research enquiry and methodology

1.6.1 Research boundaries

This study will touch on broad theoretical issues including innovation diffusion, systems innovation and energy transitions, socio-technical systems, behavioural theories and willingness-to-pay (WTP) concepts as it impacts the adoption of modern power generating technologies. The wide-ranging research areas would mean that care need be taken in order to stay within the area of interest and relevance to this study. Bryman (2012) advises locating one's study or contribution while Robson (2002) recommends establishing research boundaries from the outset with clearly stated hypothesis.

Therefore this research focuses on the potential of using PV to improve electricity supply for urban households in Nigeria. Given the level of grid maturity in Nigeria it is concerned with off-grid decentralised PV systems against grid-tied PV. It does not advocate community systems, rather rooftop PV. It is important to also stress that energy and electricity are two separate but related entities**.** Since PV is for generating power, this research concentrates on electricity for lighting and the use of appliances. It does not examine heating needs (i.e. solar thermal). This study will use both terms (energy and electricity) interchangeably in a way that will not distort the meaning of the information being conveyed.

In order to successfully address the numerous issues, the following areas will be considered in this study. Firstly the reasons behind consumer passivity towards microgeneration technologies will be explored, despite falling costs and improved efficiencies. Secondly, the key requirements for successful PV policies will be investigated using a comparative study of PV support schemes. This would entail an examination of the FITs, Renewable Portfolio Standards (RPS) and net metering incentive schemes of some leading countries. Thirdly, bearing in mind that the government cannot single-handedly fund such capital intensive projects, it explores the WTP concept as well as a brief examination of co-production and self-help theories.

It is important to also state that while the purchase behaviour is central to this research, the use behaviour is examined to aid a whole-scale design of a promotional tool. Moreover, the usage behaviour is a continuum unlike the purchase decision which can be best described as a one-off activity. It is this use-behaviour that creates the dynamics in energy efficiency models. This systems thinking approach is widely accepted as holding the key that could resolve the longstanding energy and environment dilemma that modern society faces. Thus this study addresses energy supply and demand by proposing widespread PV deployment in residential buildings as a means to altering occupant behaviour and bringing about more efficient use of energy.

1.6.2 Summary

The above cited points mean that Nigeria's centralised power network appears to be faulty. It also implies that the Nigerian government would have to take a very different and possibly aggressive approach to restoring the electricity sector in Nigeria. It further serves to elucidate on how the national power situation in Nigeria (through inefficiency and mismanagement) succeeded in creating a new kind of electricity consumer. This set of self-generating consumer would be pivotal if the power challenges are to be reversed and eventually turned into a public good.

1.6.3 Thesis layout

This thesis is structured as follows. Chapter 2 gives an account of the history, status quo and challenges of the power sector in Nigeria. Chapter 3 reviews relevant literatures including the determinants of PV adoption, innovation diffusion theories and WTP**.** Chapter 4 explores and examines different support policies; the relationships and discrepancies in an effort to aid the design of an effective and verified PV adoption tool for policymaking. Chapter 5 presents the methodology used in the study based on grounded theory and a case study approach. It details the questionnaire and interview design approaches taken and why. Chapter 6 provides the results of the surveys. The discussion chapter (7) represents the logical deduction and interpretation of the findings. Chapter 8 is the verified model for maximum PV adoption. This brief chapter is included to aid implementation of a promotion strategy for the different household groups. Finally, chapter 9 concludes the thesis by addressing the initial research questions that inspired the study. It details the implication of the results for policy and literature development and also proffers suggestions and recommendations for future research work.

Chapter 2

2.1 History, status quo and challenges of the Nigerian electricity sector

In 1896 an electrical power plant was installed in Lagos. This was the first time electricity was generated in Nigeria; approximately 15 years after its initial introduction in the UK (Ajao, et al, 2009). The next few years offered the people of Nigeria somewhat more regular power supply than is the case today. Subsequent increases in population size and improvements in economic activities following independence in the 1960s gradually resulted in power shortages across much of the country. The power challenges continued into the following decades and its persistence has crippled the industrialisation process (Iwayemi, 2008) as evidence suggests that most businesses find poor power supply more of a deterrent to investment than finance (Ohunakin, 2010).

What the above serves to illustrate is that Nigeria has had base grid power for over 100 years. Although power plants are often placed in isolated locations outside public view (Sovacool, 2009), the Nigerian grid utility has not been one of solitude and quiet operation. There has been repeated portrayal of public discontent with the body in charge-Power Holding Company of Nigeria (PHCN). However, the public disapproval of its performance has not changed much in terms of improving the grid power supply.

One thing that has started to change is that an increasing number of households in despair are opting for self-help using private generators. This sort of response was first seen in the water industry where it was reported that over 45% of households have privately-installed boreholes since the national water infrastructure failed in the early 1990s (Hall, 2006). Another industry that exemplifies consumer and private sector response to government infrastructural challenges is telecommunications, which was transformed within a space of 10 years in Nigeria (Dymond and Oestmann, 2003; Rouvinen, 2006). Nowadays, it is almost impossible to find a household that has not benefited from the telecommunication transformation, even in rural locations, as the telecom industry have planted their masts in so many remote landscapes to cater for rural dwellers.

Regarding the water industry, today many households who do not own boreholes can pay to get water from nearby neighbours; something that was unthinkable in the 1970s and 1980s. Since traditionally households have relied on the government for infrastructure projects, switching to these forms of self-help or coproduction can be seen as a positive thing. This becomes all the more rewarding if the investment of concern is a ‘green’ or environmentally-friendly one due to the public good[2] advantage. For more capital intensive projects like power supply, consumer change to more sustainable power and energy use such as the installation of a solar photovoltaic (PV) system has been slow due primarily to cost factors and dearth of support.

2.2 Status quo of current energy use in Nigeria

Electricity in Nigeria is generated from a combination of thermal plants and large hydropower (Sambo, 2008). According to the National Integrated Power Project (NIPP, 2014), the grid installed capacity in Nigeria was 10.3GW in 2013, with operational size of 6GW. Thermal plants generated about 81% of total production while the remainder was hydro-based (NIPP, 2014). The use of coal has always been insignificant with only 0.05% for year 2005 (Ohunakin et al, 2010). Given the air pollution from coal use and the present discourse on environmental quality it is doubtful that coal would suddenly be of interest to the Nigerian government.

Nigeria is also rich in crude oil and natural gas and is one of the largest exporters of this resource (CIA, 2014). Crude petroleum sales represent over 75% of the government’s revenue (World Bank, 2015; FT, 2015) bringing in close to $100b per year from 2011-2013. See Fig 2.1 for recent Nigerian oil revenues. To emphasize, daily crude oil production in Nigeria for the last 10 years has constantly averaged 2.0 million barrels (NNPC, 2010; CIA, 2014). Crude oil has always been the dominant petroleum source representing over half of total electricity generation (Shaaban and Petinrin, 2014) due to large in-country deposits, followed by natural gas (Ohunakin et al, 2010).

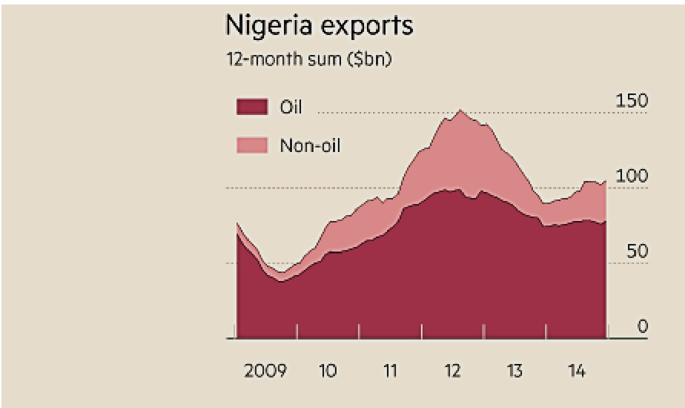

Figure 2.1 Nigerian export revenues for years 2009-2014

Source: FT (2015)

[2] Public goods are goods whose consumption does not prevent others from enjoying or consuming the good (Wiser, 1998). As a public good PV power creates net environmental benefits.

One of Nigeria's major customers is the United States of America (USA). But this is beginning to change since the US' recent discovery of shale gas in large quantities (Energy World, 2014). Fig 2.2 and 2.3 illustrates. While this may appear unfavourable for Nigeria's economy, the abundance of conventional energy resources is also attributed to the slow uptake of green power technologies in oil-rich developing countries due to lock-in[3] tendencies.

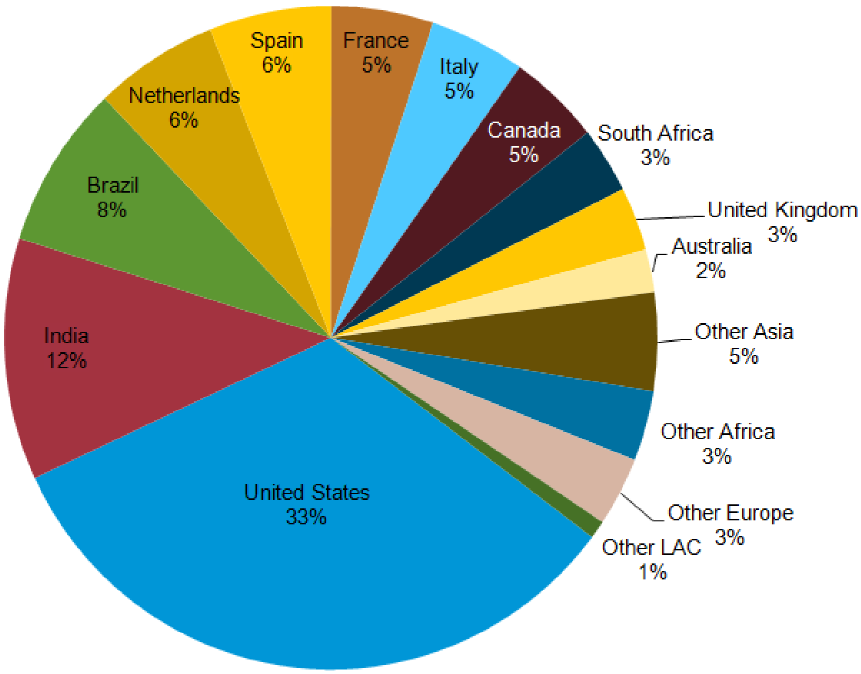

Figure 2.2 Nigerian crude oil exports by destination 2011

Source: EIA, (2014)

Note: "Other Asia" includes Indonesia, China, Taiwan, Singapore, Malaysia, Japan and Thailand. "Other Africa" includes Ivory Coast, Cameroun, Ghana and Senegal. "Other Europe" includes Germany, Portugal, Ireland, Gibraltar and Norway. "Other LAC" includes Peru, Bahamas and Curacao (EIA, 2014).

[3] Carbon lock-in is a situation where an established technology create barrier to the uptake of new technologies (Unruh, 2000).

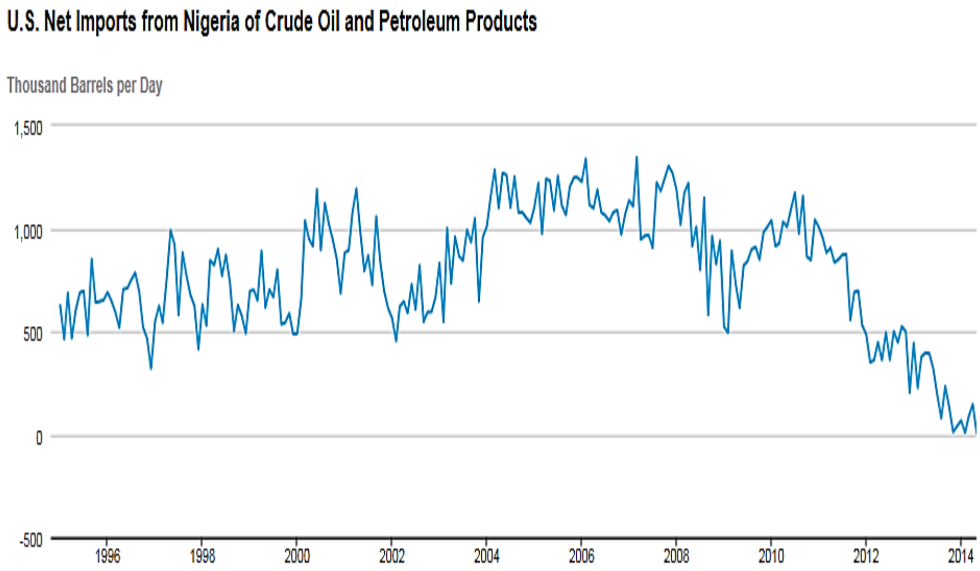

Figure 2.3 US crude oil net imports from Nigeria 1996-2014

Source EIA, (2014).

2.3 Patterns of electricity use and energy consumption in Nigeria

The provision of public infrastructures has traditionally been the responsibility of the federal government. The Power Holding Company of Nigeria (PHCN) is the body now in charge of power supply with little input from Independent Power Producers (IPP) (NIPP, 2014). Through the national grid utility, electricity is supplied to homes across the country particularly consumers in urban centres and few rural areas (Ajayi and Ajayi, 2013). This practice is common in many parts of Africa where the electricity markets are not as mature (Bugaje, 2006; Ahlborg and Hammar, 2014). The Government's plan to diversify electricity generation sources to include (RETs) is borne out of a pressure to enhance grid-supply to urban dwellers and to extend access to rural communities (Gujba et al, 2012).

Energy demand in Nigeria is a function of rising population and economic growth (Sambo, 2009). The outcome of population increase and growth in gross domestic product (GDP) of over 6% since 2008 is increased demand for electricity (World Bank, 2015). Electricity demand in Nigeria is broadly categorised into industrial, residential and commercial sectors. However, demand from the residential sector has in the past decades taken up the bulk of final electricity consumption (IEA, 2013). Fig 2.4 illustrates. This is in sharp contrast to South Africa where industry represented the largest total energy consumed for the same period (IEA, 2013)

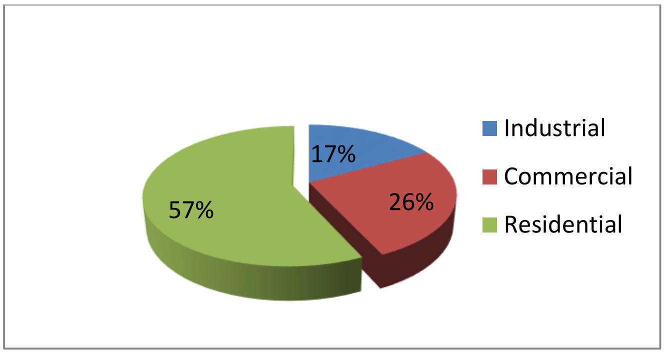

Figure 2.4 Total final electricity demand in Nigeria by sector (IEA data 2000-2011).

There are a number of explanations for the residential sector constituting over 50% of total energy demand. First, for this group central electricity is substituted with auto-generation and kerosene, while rural households rely heavily on kerosene. Secondly, in order to minimise damage to equipment from grid power outages, the commercial and industrial sectors depend heavily on private power plants and less on central electricity. Thus, if the electricity generated by industry and the commercial sector using power plants are included, the household sector will not be the largest consumer. Third, energy use inefficiency (both from a supply and demand perspective) adds to the total.

When juxtaposed against the UK in the 1970s the industrial sector represented the bulk of total final energy demand at 40%. In the 1990s its transport sector surpassed all other sectors with a total final energy consumption of 31%. The same is true for the early 2000s and in 2014 where the transport sector still accounted for the most energy use at 38%. The domestic sector was 27% with industry sitting at 13% (DECC, 2015). A similar trend can be observed in much of Europe with either the industrial sector or the transport industry representing the bulk of total demand (European Environment Agency (EEA), 2015).

Figure 2.4 above indicates that the urban residential sector in Nigeria is a very important one. Urban households generally use electricity for lighting, cooking and the use of electrical appliances. Fewer number of households utilise Liquefied Petroleum Gas (LPG) for cooking due to its high cost compared to kerosene and fuel wood. Total energy use varies greatly between households in rural areas and urban residents. Higher proportions (60%) of urban households are connected to the grid but most rural dwellers do not have access and use more biomass because grid-connection rate is approximately 10% (CIF, 2010). This low access and power shortages lead to suppressed demand (ESMAP, 2013).

2.3.1 Urban household characteristics and expenditure

The average urban household size in Nigeria is 5 (Chidebell-Emordi, 2015) and average income in 2011 was $1000 per month (Olaleye and Akinbode, 2012). The highest proportion of non-food expenditure for 2012 was on rent (36.2%), followed by power supply and cooking fuel (13.4%). Other services that households spend their earnings on are IT services and communication devices such as mobile phones and tablets (Nigerian Bureau of Statistics, 2012).

2.4 Electricity sector challenges in Nigeria

It would be misleading to attribute the failure of the Nigerian grid facility to meet demand solely on the government's use of subsidies. There are other factors that have led to the grid electricity supply constantly falling short of demand for decades (Mukhopadhyay and Odukwe, 1985; Oladosu and Adegbulugbe, 1994; Bugaje, 2006; Sambo, 2009; Ohunakin et al, 2014). The supply-demand imbalance has meant that the average per capita electricity consumption in Nigeria is small relative to many locations.

In 2009, this was given as 121kWh while that of South Africa was about 2900kWh for the same year (World Bank, 2012). Three years later, Nigeria's per capita electricity consumption rose by 29%. South Africa almost doubled its share and surpassed the world average per capita electricity consumption of 3065kWh for 2012 (World Bank, 2015). Figure 2.5 illustrates and shows comparison with other countries. Although Ghana has oil deposits it is not an oil-rich country. It was included for the sake of emphasis. Ghana has higher per capita electricity consumption than Nigeria. Thus, low access and an unstable grid network is the reason most Nigerian households utilise conventional alternative sources of self-generation.

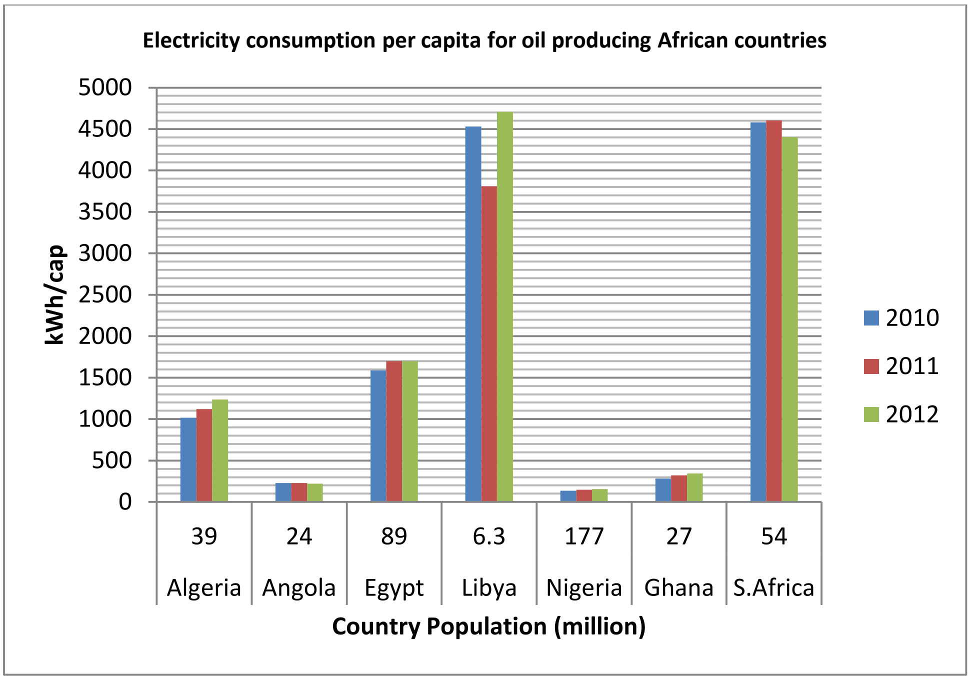

Figure 2.5 Electricity consumption per capita of some oil rich African countries

Furthermore, a report carried out by the Energy Commission of Nigeria (ECN) estimated that as at 2008 approximately 60 million Nigerians owned private generators (ECN, 2009). ECN's report further stated that these self-generating consumers incurred costs greater than $13million per year in the use and maintenance of the private power plants. A subsequent finding from another survey corroborates this. Results from a 2009 survey showed that 50% of the electricity produced in Nigeria was generated off-grid (ESMAP, 2013).

This means that roughly half of the population are reliant on auto-generation. A key reason for this problem is that the national grid infrastructure has operational capacity far below that required for the population size (177million as at end 2014) of Nigeria (World Bank, 2015). Using the minimum energy consumption capacity (i.e. benchmark of energy poverty line) required for the residential electricity needs of a population, a new interesting research proved that the generation capacity in Nigeria from 1980 to the present is insufficient even if the entire country consisted of low consumers (Chidebell-Emordi, 2015).

Aside the insufficient 6GW operating capacity there have also been reports of high power Transmission and Distribution (T & D) losses per percentage of electricity output. T & D losses to the tune of between 30-40% have been consistently reported over the years (Turkson and Wohlgemuth, 2001; Akinlo, 2009; Ohunakin, 2010; Gujba et al, 2011; Shaaban and Petinrin, 2014). The minimum reported T & D loss was 20% in 2011 (ESMAP, 2013). However, World Bank data indicates that Nigeria's T & D losses per electrical output has reduced from 17% in 2010 to 8.7% in 2012 which is a little above the world average of 8.1% (See Figure 2.6). From the graph, Nigeria presently shares similar level of losses with South Africa (8.8%) and the UK (7.9% - not shown) and is currently doing better than many countries including Brazil, Russia and India. Only China had a lower T & D loss at 5.8% per electrical output. Although Nigeria's T & D loss reduction seem to have fallen, the graph clearly shows that it represents the most erratic of all reported losses. This means that its losses are not properly managed; hence, remain unpredictable.

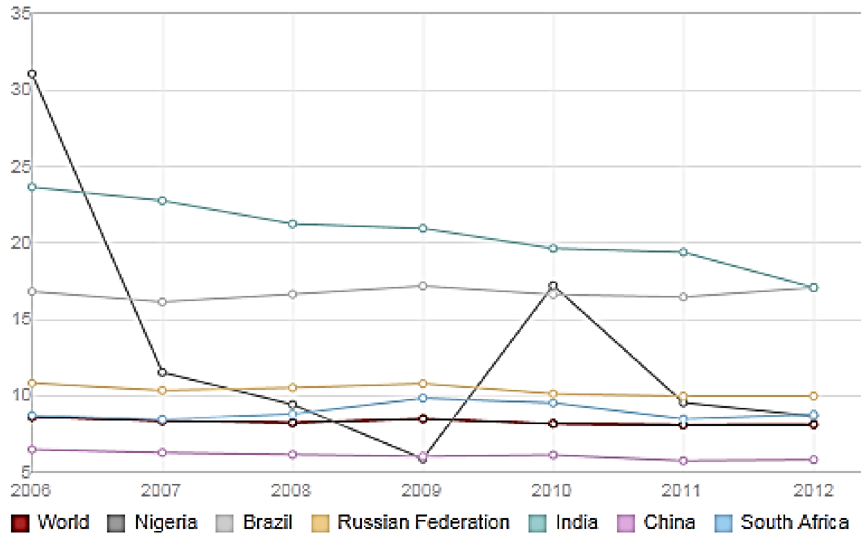

Figure 2.6 Transmission and distribution losses per unit of electrical output for Nigeria and the BRICS group for years 2006-2012

Source: World Bank Data (2015).

At the current operating capacity, the grid network is only able to meet 31% of the energy necessary for minimal use and 9.7% of the needed energy to sustain a Minimal Energy Poverty Line (MEPL) of 3068kWh/yr (Chidebell-Emordi, 2015).

Notwithstanding, network under-capacity and T & D losses, some other reasons cited in literatures for the grid power rationing, load shedding and overall shortages include:

- Poor billing and collection rates (Adeoti et al, 2001; Ikeme and Ebohon, 2005)
- Sub-optimal investment in the power industry (Ikeme and Ebohon, 2005)
- Bureaucracy, corruption and general mismanagement (Iwayemi, 2008)
- Non-replacement of outdated power generation plants (Energy World, 2014)
- Poor real-time data and slow response to technical issues (Okafor and Ezeh, 2010);
- The adoption of a sectorial model in the power sector management (Ikeme and Ebohon, 2005);
- Technical skills shortages as workforce are tied to obsolete experiences (Energy World, 2014); and
- Lack of maintenance (Ikeme and Ebohon, 2005; Shaaban and Petinrin, 2014).

2.5 Carbon emissions and intensity of power production in Nigeria

Electricity demand is a key factor used to understand capacity, generation and carbon emissions (ESMAP, 2013). Although CO_2 is not the most potent GHGs, it accounts for a significant share of GHGs (Roaf et al, 2009). Therefore reducing emissions from power and heat generation is a key objective in the climate change mitigation drive (EEA, 2015).

Carbon emissions are determined by the total amount of electricity produced in a country and the sources or generation mix. It is this mix that shows the carbon intensity which is defined as the amount of CO_2 emitted per unit of electricity generated (IEA, 2014). Compared to the world average carbon emissions of 4.9 metric tonnes (mt) the per capita CO_2 emission in Nigeria from 2009 to 2011 was relatively low at 0.5mt per capita (World Bank, 2013). This is the case even when contrasted with CO_2 emissions of other oil rich African countries. Only Ghana had lower CO_2 emissions than Nigeria but it is not a major oil producing country. See Table 2.1.

Table 2.1 CO_2 emissions of oil rich African countries

Country	CO_2 intensity (Mt/capita)	
	2010	**2011**
Algeria	3.3	3.3
Angola	1.4	1.4
Egypt	2.5	2.6
Libya	10.5	6.2
Ghana	0.4	0.4
Nigeria	0.5	0.5

However, much of Nigeria's carbon emissions come from the use of fuelwood and gas flaring during base grid power generation. Nigeria flares about 1500MMSCF (millions of standard cubic feet) per day from 170 fields (ESMAP, 2013). The flared gas can be captured and used for other purposes or the CO_2 captured and sequestrated as in the case of carbon capture and storage (CCS).

2.5.1 Nigeria's $C0_2$ emissions: Relationship with global carbon intensity

In comparison with many leading countries like the United States (US) and China, CO_2 emissions in Nigeria appear insignificant. However, it is important to note that the carbon intensities of both countries were accumulated over time. Recent statistics showed that the top 3 emitters of carbon for 2011 were the US (17.0mt per capita), Canada (14.1mt per capita) and Russia (12.6mt per capita) (World Bank, 2015). Comparing 2011 with 2010 data further revealed that the US CO_2 emissions dropped by almost 3%, while that of Japan increased by 1%. India was relatively stable at 1.7mt while for China and Russia there was a jump from 6.2mt to 6.7mt and 12.2mt to 12.6mt per capita respectively (World Bank, 2015). Table 2.2 provides the carbon intensity for BRICS, MINT and select OECD nations. Amongst the BRICS countries India was the least CO_2 emitter for both years; Brazil also fared well at 2.2mt per capita for the same period (World Bank Data, 2015). This was due mainly to its large hydropower capacity (EEA, 2015). Figure 2.7 shows CO_2 emissions per capita by region. It indicates a gradual rise in emissions from 1990-2013 for non-annex regions such as Africa, the Middle East and Latin America.

Table 2.2 Carbon intensity of BRICS, MINT and select OECD countries

Economic Group	Country	CO2 intensity (metric tonnes per capita)	
BRICS		**2010**	**2011**
B	Brazil	2.1	2.2
R	Russia	12.2	12.6
I	India	1.6	1.7
C	China	6.2	6.7
S	South Africa	9	9.3
MINT			
M	Mexico	3.8	3.9
I	Indonesia	1.8	2.3
N	Nigeria	0.5	0.5
T	Turkey	4.1	4.4
OECD	Canada	14.6	14.1
	Germany	9.2	8.9
	Japan	9.2	9.3
	UK	7.8	7.1
	USA	17.5	17

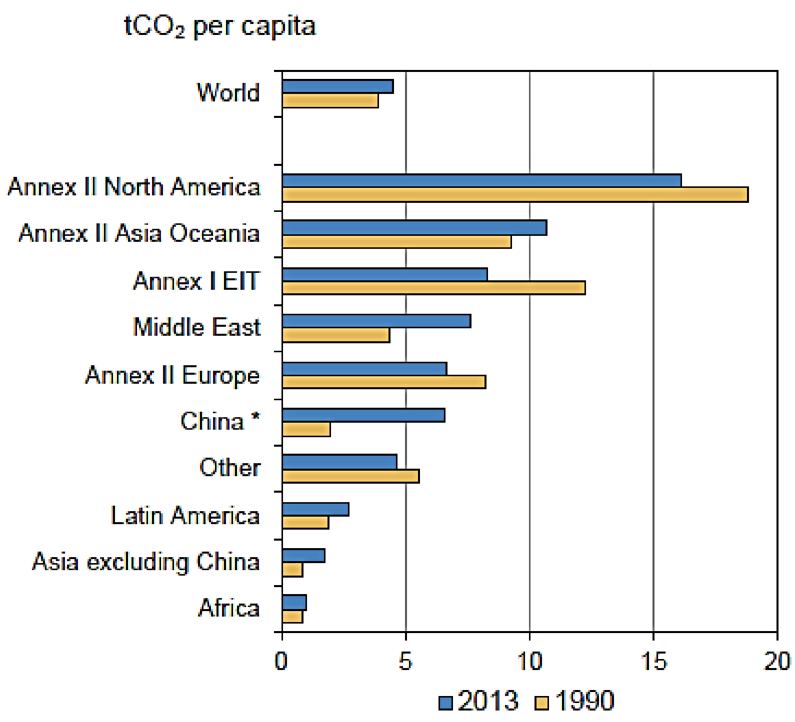

Figure 2.7 CO_2 emissions per capita by region for years 1990 and 2013

Note: China includes Hong Kong. Source: IEA (2015).

2.5.2 Carbon emission prospects of Nigeria

As the population of Nigeria increases, it becomes more industrialised and its economy continues to grow, energy use and the carbon intensity will rise in like measure. It is understood that the lure to pursue a fossil-fuel development path is cost-related. But it is not necessary for Nigeria to '*carbon copy'* the paths many advanced countries followed, which they now desperately seek to correct through energy efficiency measures.

While Nigeria is not an Annex I or II member of the Kyoto arrangement (Gujba et al, 2012) and currently has low carbon intensity, it faces the same (or worse) environmental problems as other countries. A study that assessed low-carbon development in Nigeria estimates that a low-carbon path now through year 2035 will cut GHG emissions by a massive 43% from 4,335 to 2,475mt CO_2e (million tonnes of CO_2 equivalent) (ESMAP, 2013). Thus, a move to renewables is not only reasonable, but also timely and sustainable.

2.6 Energy poverty and fuel poverty in Nigeria

Energy poverty is the reason behind the Government's, Non-Governmental Organizations (NGOs) and donor agencies' support of increasing electricity access in developing countries. It was formerly thought that this could be achieved through the use of fossil fuels due to the earlier notion of infinite resources. Nowadays, encouraging and promoting renewable energy use as well as energy efficiency is the main area of focus (UNEP, 2014). Energy poverty is detrimental to human progress and is broadly classified using two contexts: Western-Urban and Developing-Rural. The former referring mainly to social exclusion and in some cases material deprivation while the latter applies to rural locations in developing countries (Chidebell-Emordi, 2015). This means that energy poverty affects every society.

In Nigeria, urban energy poverty is not entirely a function of income. Rather, it is the result of the Government's inability to provide sufficient energy services for households. Given the presence of subsidises and the payment modes (part payment) allowed, urban households are generally able to pay for electricity supplied to their homes. Thus, energy poverty is driven by numerous factors including fuel poverty. That is, not having adequate fuel supply leads to fuel poverty.

Fuel poverty is a social problem widely seen to be linked to income poverty. So, a low-income household is more likely to be fuel poor than a middle and high income household. In the UK for instance, fuel poverty is defined as a situation where a household spends more than 10% of their income on heating and fuel bills (Boardman, 1991). Following the Hills (2012) report this definition is being reviewed so as to include other factors such as the number of low-income households and high energy costs. However, it is important to note that this definition assumes stable grid or reliable government/utility provision of energy services.

Energy and fuel poverty in the Nigerian context is slightly different from what is applicable in the UK and can be defined as the inability of a household to meet its basic energy needs (Makdissi and Wodon, 2006). Going by this definition would mean that most Nigerian households are fuel poor. The argument here is that in Nigeria both the low and high-income households suffer from inadequate power supply; hence do not meet all their energy needs. Just as energy poverty is not limited to rural areas but also to urban and semi-urban areas (Tawney et al, 2015) fuel poverty is not synonymous with income poverty (Boardman, 2013; Hills, 2012). This is because low income on its own does not explain the presence or trends of fuel poverty (Walker and Day, 2012). Therefore a household can be fuel poor but not income poor. A study in India has confirmed this to be true (Khandker et al, 2012). Fuel poverty is essentially a determinant of three household factors: income, energy prices and energy efficiency of dwellings (Santamouris et al, 2013) but should also include grid supply efficiency.

2.7 Renewable energy policy in Nigeria

The issue of the central utility frequently operating under-capacity and the resultant load shedding is widely known. Its persistence has led to the review of energy policies in Nigeria. The electric power sector reform in the early 2000s led to the introduction of a number of policies in favour of RETs (Sambo, 2008). It was through this restructuring that the role RETs could play in diversifying the country's energy portfolio was first accepted (Sambo, 2009). Pursuing a low carbon path through to 2035 will result to a 7% reduction in investment costs based on Net Present Value (NPV) calculations (ESMAP, 2013).

Evidence (Neuhoff, 2005; Sovacool, 2009; Sovacool et al, 2011) shows that as with many infrastructure projects, government support is required for PV adoption by the private sector. Widespread private sector participation leads eventually to innovation diffusion. The Renewable Energy Master Plan (REMP) initiative of 2005 was introduced as a commitment to improve power supply using renewables (Shaaban and Petinri, 2014). Under REMP, all RETs were initially set to provide 16GW by 2015 with PV generating 120MW of power (Sambo, 2008) but these targets were unmet. RETs are now targeted to generate 1GW of power by 2020 with large hydro the key area of focus (Ohunakin et al, 2015).

In addition, the roadmap for Electric Power Sector Reform Act (EPSRA) through which the vision 20:2020 plan was initiated in 2010 saw the Nigerian Electricity Regulatory Commission (NERC) announce its intention to use feed-in tariff (FIT) as a measure for promoting RETs (ESMAP, 2013; Ohunakin et al, 2014).

Another equally relevant sign of the government's plan to transform the power sector was the recent United Nations Economic Commission for Africa (UNECA) meeting for Senior Experts Dialogue (SED) held last year in Abuja, Nigeria. The theme was: "Science, technology and innovation and the African transformation agenda: Making new technologies work for Africa's transformation." The objectives of the SED included:

- Highlighting the key barriers to the development, transfer and diffusion of technologies in Africa and identifying short, medium and long term solutions; and
- Using the knowledge gained to speed up the use of new technological innovations (UNECA, 2014).

This renewed government interest and set targets of 35GW by 2020 signify substantial increase in cumulative operating capacity. However, it is unclear how this is to be implemented, as the renewable energy policies are still largely generic (IEA, 2015). As the Nigerian government is planning an increase in grid capacity, it is vital that widespread PV deployment is seriously considered. This is especially important for the residential and commercial sectors in urban centres that oftentimes have to substitute grid power with auto-generation. It is argued that it is the urban households who can help bring down the cost of PV systems through scale economies to allow for spread to rural areas.

As an innovation, PV will be pivotal to bridging the gap between power supply and demand in countries like Nigeria (CIF, 2010). Government's encouragement of PV uptake by providing a supportive environment is an avenue that can be used to re-establish consumer trust of power sector initiatives before grid expansion can be pursued. What is required is the commitment both from government and industry to support the individuals who are showing interest in this novel technology. Even if adopting households do not have the intention to contribute to nationwide supply and better environment, their individual actions translate into public good.

2.8 Future energy projections in Nigeria

Population growth is a crucial factor in energy consumption. The level of economic activity measured by Gross Domestic Product (GDP) drives a nation's energy consumption. The Nigerian population is projected to rise to 269million by 2030 (Ohunakin et al, 2010; 2014) from the current 177million. This means that within 15 years from now almost 100million people are expected to be added to the population. To cater for this number, there will be a need to make certain preparations, including expanding the grid infrastructure and improving supply and demand.

Applying the Model for Analysis of Energy Demand (MAED) frequently used to evaluate medium to long term socio-economic and demographic development, ECN projects that energy demand in Nigeria will increase substantially in the near future. As has prevailed in the last decade the household sector is expected to constitute the bulk of total energy demand until the later part of this decade. It is only after the year 2020 that the industrial sector is expected to become the major energy consumer. This assumes a 10% GDP growth rate (Ohunakin et al, 2010).

2.9 Summary

This chapter has shed light on the state of the Nigerian grid infrastructure. It has highlighted the state-of-the-art power technologies in use and the grid capacity. As with chapter one that showed the interesting gradual shifts in household preference for alternative stand-alone power systems, this chapter is further proof that the national power sector challenges has brought about this 'positive' trend. In addition to the government's renewed commitment, sustaining this development would be paramount to the success of any power sector transformation being sought. Chapter 3 reviews relevant literature and details the various theoretical concepts applied in this research.

Chapter 3

3.1 Review of related literature

This chapter discusses the various theories and key concepts used in this research, to help understand the key determinants of PV adoption at the household-level. Specifically, it reports on past researches conducted in this field of study and the results arrived at where deemed necessary. Previous findings become important as they enable the researcher to draw links by examining significant existing controversies and relationships in current literature. Therefore, this chapter investigates consumer responses to PV adoption with or without government incentives.

Different theories have been used to explain the determinants of PV adoption and Microgeneration Technologies (MGTs) in general. The most common theories that have found application in literature include the innovation diffusion theories, consumer attitudes or response theories and socio-technical systems. Since it is the objective of this study to encourage increased PV uptake, the chapter examines the willingness-to-pay (WTP) concept. This is particularly important for a country like Nigeria where the PV industry is largely unsubsidized despite favourable geographic and climatic conditions. Also, the WTP concept becomes critical, as given the unstable grid, there would be a need for battery power storage by adopting households, thus adding to total costs of acquiring a PV module.

Innovation diffusion theories are often used when the goal is market penetration and explained using yardsticks such as installed capacity and market share etcetera (Reddy and Painuly, 2004; Lüthi, 2010). Other studies examining the slow pace of PV and general green power diffusion have relied on the energy transition frameworks as the primary theoretical medium (Lund, 2010; Fouquet, 2010; Fouquet and Pearson, 2012). Many studies combine some of these theories in their treatise when investigating the barriers to and drivers of PV uptake (Salmela and Varho, 2006; Claudy et al, 2011; Yamamoto, 2015). Often, researchers use consumer attitudes and behaviour with WTP theories. However, in relation to the hindrances to widespread PV diffusion, particularly at the national or firm level, innovation diffusion theories are mainly resorted to.

Another important theory, especially regarding its role in infrastructural development, mainly in developing countries, is the concept of coproduction. But, it has found limited application in PV promotion studies (Sauter and Watson, 2007). Likewise, the notion of self-help has not been used to examine the factors impacting PV adoption and diffusion. This research examines both concepts because of their relevance to the geographic location under investigation. Aside location and stage of economic development, the idea of self-help can be context-based and hence region-specific. In this chapter, the above enumerated theories and related concepts will be explored.

3.2 PV adoption and diffusion theories

Conceptual models deployed in PV diffusion studies from the end-users' standpoint are predominantly based on social psychological perspectives (Labay and Kinnear, 1981; Arkesteijn and Oerlemans, 2005; Jager, 2006; Faiers and Neame, 2006; Claudy et al, 2011). Fewer studies are embedded in economic principles (Wiser, 1998, Sauter and Watson, 2007; Sardianou and Genoudi, 2013). Behavioural perspectives can be broadly categorised into two groups; the intention model and the innovation diffusion models.

The economic model is founded on the classical economic theory of utility. It is centred on rational choice. It assumes that given capital constraints consumers make consumption decisions based on least cost and welfare maximisation (Wiser, 1998). It further views the performance of any purchase behaviour as a reflection of an individual's underlying needs. This need is driven by the quest to maximise the satisfaction gained from consuming the product or service concerned. Thus, for any demand for a good or service, there is a conflict with an alternative good or service, as the scarce financial resource faces stiff competition from both desired goods (Sardianou and Genoudi, 2013).

This situation elevates the consumer to a chief position, requiring the consumer to make purchase decision based on the good that provides the most utility (Sardianou and Genoudi, 2013). Under such conditions, a household's decision to adopt PV may impact on the satisfaction of several other needs, such as: subsistence, participation, identity, understanding, protection, leisure and freedom (Arkesteijn and Oerlemans, 2005). This implies that the adoption of an innovation is associated with the needs it will help satisfy. Other applicable needs include energy cost savings (Keirstead, 2007; Komatsu et al, 2013; Hast et al, 2015) and energy autarky (Balcombe et al, 2013).

A key aspect of PV technology's profile which impacts uptake is its high upfront costs and long payback time (Lüthi, 2010). High initial costs of PV systems act as a disincentive to uptake. Due to the initial cost implications of PV as at the time of purchase, it yields negative outcomes, while some desirable outcomes are deferred (Jager, 2006; Abdullah and Jeanty, 2011). Thus, PV represents a high involvement purchase for most individuals (Rundle-Thiele et. al, 2008). In addition, consumers do not only measure costs in monetary terms; the time committed to searching for information and installation duration are also crucial in the PV adoption decision (Jager, 2006). For households in developing countries in particular, low income and purchasing power would mean that the capital-intensive PV becomes unaffordable for many (Komatsu et al, 2011).

Aside capital cost as a deterrent to PV adoption, the influence of the notion of time on intertemporal choice[4] has been shown (Berns et al, 2007). Payback time (PBT) can be extremely important in investment decisions. Overall, people tend to prefer shorter PBT for their investments. But PBT is only a part of a bigger consumer motive. An example of PBT not making much of a difference has been shown in the UK, where lower PBT for wall insulations did not result in increased investments (Sauter and Watson, 2007). This means that there are other factors necessary for consumer uptake beyond economic factors. The rational choice theory has been criticised mainly by behaviourists, who argue that consumers do not make decisions solely on economics, but also as a result of ethical and environmental worldviews (Claudy et al, 2011).

As an intention model, Ajzen's (1991), theory of planned behaviour or reasoned action is one of the most frequently cited in technology adoption and innovation discourses. It has been hugely successful in explaining and predicting consumer behaviours and has found application in many fields including innovation diffusion studies in healthcare (Fitzgerald et al, 2002), telecommunication (Rouvinen, 2006) and education sectors (Cohen-Vogel and Ingle, 2007). The theory of planned behaviour proposes that attitudes (such as, perceived reputation of utility suppliers), subjective norms (e.g. concern for environment) and perceived control (e.g. technology affinity) drive behaviour. Attitudes, norms and perceived control impact intention and subsequently behaviour (Leenheer et al, 2011).

Ajzen's theory also suggests that aside norms, knowledge is also crucial in the formation of consumer attitudes including the formation of 'green' attitudes (Rundle-Thiele et al, 2008). This theory is vital in that it helps to reveal the key motives and characteristics of households who choose to generate their own power sustainably. In terms of meeting home energy needs, households must make PV purchase decisions based on a number of factors including: cost, reliability, values, attitudes, energy use

[4] Intertemporal choices are decisions that have consequences which reveal themselves over time.

behaviour, income, household size and availability of government subsidies etc. This long list of considerations adds to the complexity of the decision-making.

Consumer purchase decisions of products requiring less time and cognitive effort are often quicker to reach than those that entail high mental effort. In other words, consumers do not act on impulse in most such purchases. Moreover, the views and opinions held by consumers on energy generation technologies are not held in isolation (Howell et al, 2014). They are based on the available information, especially regarding other energy options (Sovacool, 2009; de Best-Waldhober et al, 2011). Thus, applying high cognitive effort helps minimise the risk of post-purchase dissonance (Faiers and Neame, 2006).

For these reasons, the adoption decision of a technology such as PV is considered to be a high-involvement one (Jager, 2006). Although referring to PV as high involvement creates the impression that it is difficult to use, Jager's use of the phrase means that PV requires more attention from adopting households than conventional power supply. The planned behaviour theory is relied upon in such situations where the outcome of a decision seems to be a very important one (Jager, 2006); in this case, providing reliable electricity using more sustainable power systems. Therefore, the performance of any behaviour is greatly dependent on the anticipated outcomes linked to that behaviour (Berns et al, 2007).

The second group of the social psychological perspective is the diffusion of innovations model (Rogers, 1995). It is also referred to as the hierarchical model due to the step-by-step approach it suggests (Arkesteijn and Oerlemans, 2005). Under this model, diffusion is defined as the process through which an innovation is communicated via certain channels over time through a social system (Foxon and Pearson, 2006; Faiers and Neame, 2007). This innovation may be an idea, product, process (or a combination of these) but does not necessarily have to be new, as long as it is new to the adopting community (Friebe et al, 2014).

The innovation concept can be examined from various perspectives including product attributes, time and speed of uptake and characteristics of adopting population (Motawa and Banfill, 2011). Diffusion is the relative speed with which an individual adopts a product or service compared to other members of the same social system or society. Because of this time dimension, the speed of adoption is taken to be a function of certain attributes that the innovation possesses. These include: relative advantage, perceived risk, complexity, compatibility, trialability and observability (Claudy et al, 2011).

Relative advantage is used to refer to the marginal benefits the innovation has over the existing one it is intended to replace. Perceived risk is associated with consumer perception of the likelihood of economic or social loss that may arise from the innovation. Complexity relates to the difficulty of understanding and using the innovation and can be a restrictive factor in adoption decision (Labay and Kinnear, 1981; Faiers and Neame, 2006). Compatibility is used to describe how the innovation fits into the values of the adopter and the existing networks. Trialability refers to the short-term trial period the innovation allows before purchase, while observability is the extent to which the innovation is visible to others. While all other attributes can be seen in many innovations, as an experience good, solar PV does not benefit from the trial-before-use feature. The usefulness of the relative advantage attributes of an innovation was challenged on the grounds that the 'relative advantage' attribute is non-specific and can mean anything (Claudy et al, 2011).

However, because consumers have certain expectations for products and services, Rogers' pioneering work points to the relevance of perception in the innovation adoption decision. In the case of PV, consumers also have certain expectations from the government, in terms of information provision, regarding energy-environmental-climate issues and incentive support (Zografakis et al, 2010). Rogers' study demonstrates that consumers' perceptions are a key determinant of the rate of diffusion. The speed with which an individual goes through the adoption process is determined by the technology's attributes and the inclination of the individual to accept the innovation (Faiers and Neame, 2006).

Unlike larger renewables e.g. large wind turbines, where social acceptance is of extreme importance in investment decisions (Yuan and Ma, 2011; Howell et al, 2014), for micro-generation, it is individual acceptance that matters (Sauter and Watson, 2007). This acceptance is derived from the value the potential adopter attaches to the technology and the expected benefits derivable which is based on their knowledge. Thus, early adopters tend to place a higher value for an innovation that is not solely based on cost, but on the worth that the innovation is to them (Sauter and Watson, 2007).

Since every individual does not adopt the innovation at the same time, Rogers' (1995) divided the stages of adoption into five categorises according to consumer personalities, values and behaviour (Faiers and Neame, 2006). Within this five-stage category and in ranking order are the innovators, early adopters, early majority, late majority and laggards (Figure 3.1 details). The first two (innovators and early adopters) are considered very important as they indicate consumers who show the most initiative in the adoption process but they are often smaller in number. Their innovativeness in the adoption process is attributed to their level of awareness and higher education (Faiers and Neame, 2006).

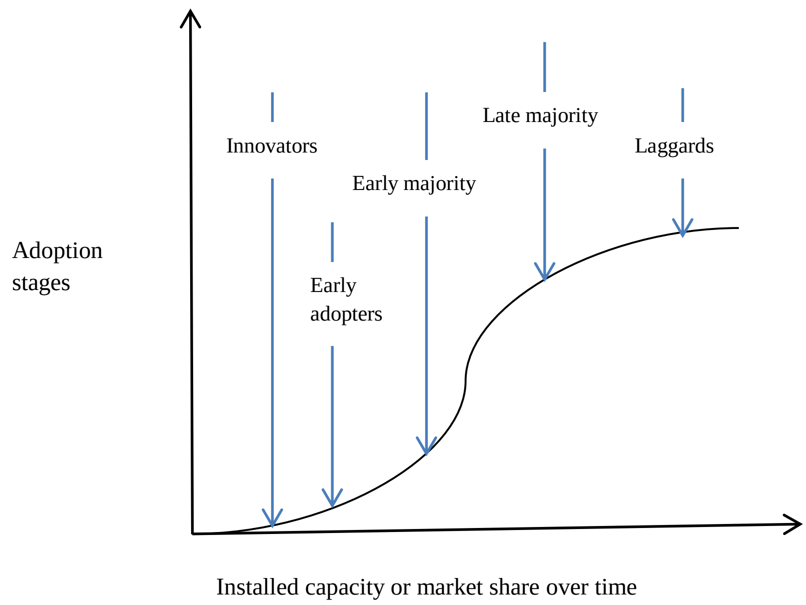

Figure 3.1 A representative model of Rogers' (1995), Innovation diffusion S-curve

3.2.1 National and firm-level innovation diffusion theories

Studies have shown that the hindrances to the adoption of a novel technology and innovation occur in relation to government policy miscalculations as well as the firm level resistance (Sovacool, 2009; Lüthi, 2010). Often the major barrier to the diffusion of an innovation at the national and firm level is the dominant design. The reason for this is that current technologies that have existed for decades or even millennium are already established, making it difficult for a shift to novel, more sustainable technologies with greater benefits (Jacobsson and Lauber, 2006). This is the case in all kinds of innovative technologies including telecommunications. The old landline telephone technologies used pre-1980s were stable and locked-in (Geels, 2005) until the advent of mobile telephony.

Therefore, hindrances to the diffusion of PV arise from scale economies, path-dependency and policy inertia (del Rio and Unruh, 2007; Lüthi, 2010; Bolton and Foxon, 2015). Carbon lock-in is the chief reason why the diffusion of PV has been slow despite over 50% consumer shown preference for renewables in many locations (Pichert and Katsikopoulos, 2008; Kaenzig et al., 2013). In addition, organizations or utilities will usually resist or reject new radical technologies that they perceive to be disruptive (Christensen 2006; Sovacool, 2009). This is because institutions have huge influence on the path an innovation follows (Edquist, 1997; Sovacool, 2009). The influence exerted by power-wielding individuals or actors in many institutions have considerable impact that hinders the diffusion of novel technologies (Foxon and Pearson, 2008).

Diffusing a new technology and judging how well a new technology disseminates often depends on scale effects, learning-by-doing, learning-by-using and learning-by-interacting (Geels, 2005; Rivers and Jaccard, 2006; Shum and Watanabe, 2009). Increasing returns to scale are most favourable at the early stages of the development of an innovation due to the role of feedback. Feedback received from early adopters can help product manufacturers improve the products as well as give them competitive edge to gain significant market share. However, it is this scale effect that can easily lead to lock-in tendencies (Bolton and Foxon, 2015).

When institutions struggle to promote a new technology because of path-dependence and when the new technologies are hurriedly implemented due in part to bounded rationality[5] circumstances leading to market failures result. Market failure arises as a result of not properly implementing change. Market failures take place when energy prices do not take into full account the negative environmental and social costs of production. Moreover, even if the environmental and social costs are accounted for, conventional fossil-based power generation and use have side effects that are greater than zero **(**Sovacool, 2009**)**. There are 2 key market failures and they arise from concerns about knowledge spill-over and negative externalities (Foxon and Pearson, 2008). Knowledge spill-over concerns the ease with which a new innovation can be copied leaving the innovators unable to reap the full benefits of their ideas (Rivers and Jaccard, 2006). Negative externalities and knowledge spill-over are the major reason

[5] Limited ability of individuals, organisations or governments to obtain and process information to aid decision making.

governments support niche technologies through R & D and promotion incentives such as Feed-in-tariffs (FITs) and Renewable Portfolio Standard (RPS) to control the situation (Wiser, 2007).

3.3 Systems innovation and socio-technical systems

Systems Innovation (SI) was conceived as a means to correct market failures by merging innovation and environmental policy concepts. SI is the (study of) elements and relationships that interact in the production, diffusion and utilisation of new and economically useful knowledge (Geels, 2005). In recognition of the inseparable interrelationships between technological systems - the grid infrastructure, buildings, and society, the systems model was recommended. These different aspects and processes interfere and interact with each other to the point that one cannot be dealt with without the other. Hence, a singular model or approach (like that formerly used under disciplinary perspectives for addressing issues with domestic energy consumption) would be inadequate to provide the necessary improvements to electricity supply and demand and the larger scale electricity networks.

Systems innovation adopts an integrated perspective and is often proposed because it is seen as instrumental for bringing to an end disjointed and failed policy regimes (Foxon and Pearson, 2008). SI framework has promise to help lead to faster transitions in climate mitigation and energy efficiency goals. Novel technologies are vital for SI because they plant the seeds for the necessary change (Geels, 2005). The term systems innovation is described in literature using various terminologies that refer to the same thing. Jacobsson and Johnson (2000) preferred using technological systems to denote SI. Irrespective of the differences in the terminologies used by the researchers, a key feature in their description is that they all indicate the interconnectedness between technology, individuals and society in the innovation diffusion process.

This understanding has resulted in the increased view of PV innovation as socio-technical. The socio-technical system viewpoint has been in existence for over 20 years (Hughes 1987; Hitchcock, 1993). Hughes' study spearheaded the call for a more integrated approach that encompasses the social, economic, technical and political dimensions of energy generation and use. However, in recent years it has taken on fresh meaning as more researchers begin to see its relevance towards helping to resolve the energy trilemma of affordability, sustainability and security.

The socio-technical systems perspective simply refers to combining the economic, socio-cultural and technical perspectives in the conviction that by fusing ideas from the physical sciences, economics, sociology, psychology and innovation diffusion studies, a more lasting solution can begin to surface (Sovacool, 2009). It should be noted that some researchers sometimes use the term loosely to mean SI (Mondal et al, 2010). Similar to large technical systems, solar PV is a socio-technical system. Using socio-technical approaches in renewable energy studies is becoming increasingly common (Sovacool et al, 2011; Nguene et al, 2011; Sorrell, 2015). Most recently, Crossland et al, (2015) used socio-technical approaches to investigate ways to improve off-grid PV battery life for rural communities in Rwanda.

It is thought that the socio-technical framework can provide profound understanding of the power supply and demand challenges and its related processes (Sorrell, 2015). Socio-technical perspectives are useful when the actions of individuals and technology are intertwined (Müggenburg, 2012) and only a socio-technical approach can allow for the fulfilment of societal functions (Verbong and Geels, 2010). WTP is one grounded theory often used to explore societal acceptance of a novel power technology in consumer response studies. This concept is explored next.

3.4 Willingness-to-pay

WTP in this study refers to the value to households for the option to buy PV system or RES-E for a specified amount. It is used to show how much consumers are prepared to pay so as to meet a specific improvement in environmental quality or receive an identified supply of a good or service (Yoo and Kwak, 2009). Many studies addressing the barriers to PV adoption and consumer response to generic renewable power technologies have applied the WTP concept (Oliver et al, 2011; Lenheer et al, 2011; Sardianou and Genoudi, 2013).

Literature largely represents willingness-to-pay for PV, microgeneration technologies (MGTs) and RES in general as dependent on a number of factors. Some of the most common determinants mentioned are prior knowledge or awareness (Zografakis et al, 2010; Mondal et al, 2010; Komatsu et al, 2011), output limitations and technical support (Close et al, 2006; Faiers and Neame, 2006), climate change concerns (Rundle-Thiele et al, 2008; Leenheer et al, 2011), initial costs (Balcombe et al, 2013) and availability of fiscal support incentives (Jager, 2006; Zhao et al, 2012). Aside, the socio-cultural, technological, environmental and economic factors impacting WTP and adoption decision, the role of regulation and supportive institutions have been repeatedly referenced (Keirstead, 2007; Sovacool et al, 2011; Ohunakin et al, 2014).

One of the foremost studies in this millennium is the research conducted by Nomura and Akai, (2004) in Japan. Their research used Contingent Valuation Methods (CVM) to analyse household WTP a higher amount for renewable electricity including PV generated power. They reported using mail questionnaires but did not specify type. For instance, whether postal, email or hand delivery. As at the time of the study, the Japanese government provided roughly 31% subsidy for adopting households. The researchers found that Japanese households placed a very high value on PV electricity with an affirmative propensity to pay for any RES-E. Notwithstanding the high costs households preferred residential roof-mounted PV.

They further pointed out that the households who see future prospects and believe more people will participate show greater WTP than others. This is referred to as the participation expectation or bandwagon effect as acknowledged by Wiser (2007). Although frequently used in explaining consumer drivers for RES-E, fewer studies have used the WTP theory specifically for domestic microgeneration systems (Faiers and Neame, 2006; Scarpa and Willis, 2010; Claudy et al, 2011; Leenheer et al, 2011). Most studies concentrate on renewable electricity (i.e. grid-supplied green power) (Nomura and Akai, 2004; Borchers et al, 2007; Yoo and Kwak, 2009; Oliver et al, 2011; Guo et al, 2014). This is particularly the case where the electricity markets are deregulated to allow consumers the opportunity to choose supplier. However, the motive for the studies are all related and is essentially to increase the adoption of a more sustainable power source.

Awareness impacts adoption as it precedes it. Affordable access to relevant information can impact consumer opinions on RES-E. Salmela and Varho, (2006) argued that the environmental impact of RES-E be made clear to consumers as the messages are oftentimes distorted leaving consumers unsure. WTP has been shown to increase when consumers have optimistic attitudes about RES-E (Hansla, et al, 2008). The need to incorporate social influences as a means towards understanding what determines consumers' WTP has been further proposed (Sovacool et al, 2011). This awareness concern as a hindrance, is not only in terms of renewables and level of economic development of a country, as Sovacool confirmed in a study in USA where only 12% of people could pass a 'basic' electricity-literacy test (2009).

Overall energy and electricity knowledge has been shown to be low due to the abstract nature of electricity, lack of vital information and insufficient promotion campaign (Hite et al, 2008). Although above average earnings and high educational attainment assist investors in their decision, both factors do not make for an awareness or understanding of microgeneration technologies (Baskaran, et al, 2013).

PV power is dependent amongst other things on solar radiation levels which can vary depending on location and time of day. This affects output, hence the reason for power storage in many installations. This intermittency or variability of RES, especially wind and solar, has been found to impact investment, but not enough to discourage adoption, as found in Greece (Zografakis et al, 2010). Intermittency or variability is not limited to renewables. It can affect conventional power sources too. Furthermore, intermittency can be predicted, managed and mitigated (Sovacool, 2009).

Similarly, WTP has been found to increase with the level of environmental consciousness (Ek, 2005; Rundle-Thiele et al, 2008; Guo et al, 2014). Altruistic motives were found to be important in Japan where up to 90% of households thought fossil fuel-linked environmental problems were real and needed to be mitigated[6] (Nomura and Akai, 2004). This is dissimilar to the findings by Oliver et al, (2011) who used regression analysis to evaluate residential consumers WTP a premium for green electricity and revealed the existence of the free-rider[7] problem. Although free-riding is inevitable (at least for now) in most places, many South African consumers were found to hold the view that everyone should contribute equally to improving environmental quality and promoting climate change mitigation. This implies that adoption decision here would be driven by factors external to altruism or the environment. Thus notwithstanding, studies have shown that consumers are generally interested in RES (Scarpa and Willis, 2010).

Marginal consumer WTP for renewables has also been found to differ by generation source. In situations where consumers were presented with the opportunity to choose from a range of unconventional energy technologies, preferences have varied (Claudy et al, 2011). In a Swedish study, positive willingness-to-pay was reported for wind energy (Ek, 2005). In contrast, some other studies pointed to consumers showing higher

[6] It is noteworthy that such an impressive display of altruism was shown way before the Fukushima nuclear disaster of 2011.
[7] Under voluntary payment schemes, few individuals will be willing-to-pay for a good that benefits everyone.

preference for solar generated electricity than for wind energy (Nomura and Akai, 2004) and for wind and biomass (Kim et al, 2012; Borchers et al, 2007).

It is hard not to notice the parallels between these studies and that of Komatsu et al, (2011) who applied WTP in their research using South Korean households. Their goal was to demonstrate the possibility of households' WTP differing by renewable electricity source. They found no significant difference between the WTP for wind, hydropower and solar PV. Instead, they concluded that consumers were more concerned about a reduction in total power supply costs. In Alabama, United States, Hite et al, (2008) evaluated consumer WTP for biomass and found that consumers are WTP a premium but many lack prior information.

Findings from a UK study using conjoint or Discrete Choice Experiment (DCE), showed households' valued RETs but that the value was not adequately high enough due to the huge expense tied to these technologies (Scarpa and Willis, 2010). This is unlike the findings in a Swiss study where households' value and WTP for energy saving measures were significantly higher (Banfi et al, 2008). Another UK study revealed that the experience consumers have on green energy sources was stated as having an influence on WTP a premium (Batley et al, 2001).

These environmentally friendly technologies are seen to have the potential to help mitigate climate change and global warming (Stern, 2007; Sovacool, 2009). In fact, a study in Japan proved that PV adoption by households could cut GHG emissions by 7% (Ida et al, 2014). This has led to increased campaign and greater awareness by the Japanese consumers of the potential of PV. As a result, the role of PV towards reducing carbon emission is a significant motivation to install PV in Japan (Ida et al, 2014). While many citizens would want to participate in reducing carbon emissions, capital costs remain an obstacle. This means that ways by which households can be encouraged to pay either directly or indirectly becomes vital, hence the need for incentives.

Using CVM, Wiser (2007) investigated the WTP for RES-E through voluntary and collective payment arrangements under government and private provision of RES-E. Wiser recorded a higher WTP under collective payment mechanisms than through private provision. CVM is a well-known elicitation tool used in surveys to show consumer revealed or stated preferences for public or non-market goods (Wiser, 2007). As shown in the summary Table 3. 1, CVM finds widespread application. Also applying

CVM, Yoo and Kwak (2009) examined the value of increasing the use or household subscription to RES-E in Korea and reported a high WTP.

Table 3.1 Summary of recent studies on consumer attitudes, responses and WTP for microgeneration technologies (MGTs) including PV

Study and year	Location	Sample size and group	Technologies investigated	Research aims/objectives	Methods	Analysis	Key findings
1.Yoo and Kwak, (2009)	South Korea	800 households	Green electricity	Assess the economic value of using policy to increase adoption	Face-to-face interviews; CVM	Mean average WTP	High WTP shown with economic benefits
2.Claudy et al, (2010)	Ireland	984 consumers	Six MGTs including solar PV, SHW and micro turbines	Evaluate the role of awareness and demographics on consumer adoption of MGTs	Dichotomous choice (DC) mode of WTP elicitation	Logistic Regression (Ordered Logit Model)	Awareness differs by MGTs with a higher awareness revealed for PV. Older citizens show greater WTP
3. Zografakis et al, (2010)	Greece	1440 households	RES-E	Investigate public acceptance and WTP for RES-E in Crete	Interviews; CVM; Double bound DC used to elicit WTP	Mean average WTP	High income and Energy awareness are vital. Power shortages positively correlate with higher WTP
4. Scarpa and Willis, (2010)	UK	1279 UK households (excludes NI)	MGTs	Examines WTP for MGTs	Interview (Computer assisted)	Choice experiment	Households value MGTs but value not high enough to prompt adoption due to investment costs
5. Abdullah and Jeanty (2011)	Kenya	200 rural households	SHS and grid electricity	Investigates WTP for PV and grid electricity	Close-ended questionnaire; CVM Double bound (DB) DC	Regression analysis	High cost and low access to loans are barriers; Education and home ownership positively impacts adoption
6. Oliver et al, (2011)	South Africa	543 Cape town households	Green electricity	Investigates household WTP a premium for grid-supplied green power	Grounded theory used in design of questionnaire	Spearman's Correlation	High earners show higher WTP. The perception that green power is reliable and the view that everyone should participate drives uptake
7. Tillman and Schweizer-Ries (2011)	Uganda	139 Ugandan stakeholders	Solar Home Systems (SHS)	Impact of effective knowledge transfer on PV diffusion	Questionnaire	ANOVA and correlation	Beliefs, misconceptions and lack of technical knowledge on the part of installers and users affect SHS use

8. Leenheer et al, (2011)	Netherlands	2047 Dutch households	MGTs	Evaluates consumer attitudes towards self- generation	E-questionnaire with multiscale measures	Regression analysis	Environmental concerns significantly drives own power generation. Power outages do not
9. Kim et al, (2012)	South Korea	720 households	Wind, PV and hydropower	Investigates WTP in the presence of RPS policy	Face-to-face interviews; CVM bidding using DBDC	Mean average WTP	WTP differs by technology source albeit insignificantly; Average WTP over 3x higher than monthly conventional electric bill
10. Komatsu et al, (2013)	Bangladesh	305 rural SHS households	Solar Home Systems	Analyses factors that impact user satisfaction	Door-to-door survey	Econometric (Ordered Probit Model)	System and battery reliability, quality products and energy savings and reduced replacement time correlates with higher satisfaction
11. Sardianou and Genoudi, (2013)	Greece	200 households	RETs including solar, wind & geothermal	Investigates the factors impacting WTP for RES	Cross-sectional data	Binary Probit Regression Model	Rising electricity costs increases WTP. Financial incentives are vital but tax deduction is preferred
12. Ahlborg and Hammar, (2013)	Tanzania and Mozambique	17 interviews with power sector actors (excludes users)	Off-grid RETs	Explores the barriers and motives for rural electrification using RETs	Qualitative methods	Qualitative	Country-specific drivers and barriers identified. Technical difficulties and donor dependency are barriers
13. Guo et al, (2014)	China	700 households	Green electricity	Investigates WTP for RES-E	Face-to-face interviews; CVM using DBDC	Multivariate Logit; Mean average WTP	Environmental concerns positively impacts WTP. Average WTP 3x higher than monthly electric bill
14.Hast et al, (2015)	China	232 consumers	MGTs and green grid electricity	Explores Shanghai's consumer attitudes to RES-E	Online questionnaires	Binary and Multinomial logistic regression	High costs and product quality issues remain a barrier. Energy savings and energy security cited as motives
15. Yamamoto (2015)	Japan	488 consumers	Solar PV	Study appraises the role of interpersonal communication on WTP	Online questionnaires	Comparative analysis	Opinion leaders significantly influences uptake. Subsidy more effective than reliance on FIT

WTP: Willingness-to-pay; SHW: Solar hot water; RETs: Renewable energy technologies; RES-E: Renewable energy sources-electricity; DBDC: Double bound dichotomous choice

Some consumer-related studies in Africa have made use of the WTP concept. It has previously been used in Ghana to gauge demand for improved healthcare (Lavy and Quigley, 1993), in Kenya for agricultural purposes (Kimenju and De Groote, 2008), biodiversity in South Africa (Turpie, 2003) and for the provision of water services in Nigeria (Whittington et al, 1991). Its application in African studies is fast growing. Using discrete choice experiment Abdullah and Mariel (2010) investigated consumer WTP for improved conventional grid electricity services in rural Kenya. It should be noted that while there is a remarkably high prevalence of private provision of public goods in Africa, few studies have considered its use in the renewable energy sector. This is a ***key contribution*** of this study.

One of the most recent publications examined the drivers and barriers to grid extension, off-grid systems and RES for purposes of rural electrification in Tanzania and Mozambique (Ahlborg and Hammar, 2014). They reported private-sector disinterest and donor dependency as barriers. In another study in rural Kenya, using CVM Abdullah and Jeanty, (2011) compared WTP for grid electricity and solar home systems (SHS)[8]. They reported that higher preference was shown for grid electricity against centralised PV supply. They further stated that households preferred small monthly payments rather than bulk payments that PV electricity would require.

There were other factors hindering WTP in relation to technical expertise, knowledge transfer and communications as was detailed by Tillmans and Schweizer-Ries (2011) in their study in Uganda. Another reported consumer frustrations about PV power limitations in a leasing scheme in South Africa (Lemaire, 2011). The author said it was because the adopters misunderstood or were not well-informed about PV power limits. It was further related to the high level of electrification in South Africa making for unreasonable expectation such as wanting to use PV for cooking and heating. Such problems are not particular to Africa. Sovacool et al (2011) gave a detailed account of similar problems in Papua New Guinea where rural households chose pigs and poker chips over PV panels.

The influence of socio-demographic factors has been assessed in related energy studies (Abrahamse and Steg, 2009). There seems to be a correlation between WTP and certain sociodemographic factors including age, income, education, home ownership, household size, dwelling type and likelihood of moving home. Sardianou and Genoudi

[8] Term used to describe small PV systems <100W installed in many rural locations.

examined the factors that affect consumer intention to adopt RES in Greece and reported that age, income and education were important drivers (2013). Gender and marital status were statistically insignificant in the adoption decision. Oliver et al (2013) also showed that higher income earners were more likely to pay a premium for green electricity in Cape Town.

However, many researchers suggest that attitudinal constructs are better predictors of WTP than household characteristics (Sauter and Watson, 2006). Some argue that actual product uptake in attitudinal studies are overestimated (Rose et al, 2007). The overestimate results in hypothetical bias (Wiser, 1998; Abdullah and Jeanty, 2011). In addition, stated or revealed preference does not always lead to uptake in all cases in real life situations (Salmela and Varho, 2006; Sardianou and Genoudi, 2013). However, given the concealed nature of consumer preferences, the only practical way to elicit and measure choices is by WTP (Berns, et al, 2007).

3.5 The state of solar energy research in Nigeria

In the past 25 years, several studies have been carried out on the poor energy supply infrastructure in Nigeria and the need for energy transition using solar energy and other renewables (Mukhopadhyay and Odukwe, 1985; Adurodija et al, 1998; Ohunakin et al, 2010). A number of these studies have shown that given the high solar radiation, Nigeria can benefit from widespread PV utilization in rural areas (Adeoti et al, 2001; Oparaku, 2002; Chineke, 2008; Fadare, 2009; Shaaban and Petinrin, 2014) and for urban household-level electricity generation (Fagbenle et al, 2003). All of the studies also point to a preference for large scale central supply.

In addition, the studies also have one thing in common. They all emphasized the positive impact that PV use beyond government demonstration projects will make in Nigeria. Analysis of these studies revealed opportunities for improvement in the PV promotion agenda. Firstly, although a recent publication researched hindrances to PV diffusion in Nigeria (Ohunakin et al, 2014) none of the listed studies investigated the barriers to urban household PV adoption in Nigeria, and how uptake can be accelerated through this group. Secondly, most of the studies focused on technology-oriented issues and supply-side factors to the neglect of demand-side response and self-generation. A notable *research gap* this study aims to exploit.

On the international scene, some studies exist on the barriers to PV and other RETs adoption and the motives for PV and other RETs uptake. However, a majority of these studies are concentrated in more advanced economies, particularly the US, Japan and Europe (Leenheer et al, 2011; Zhao et al, 2012). But the barriers to PV deployment and motives for PV deployment can differ across countries and regions. The author argues that the reason most local and international studies have disproportionately focused on rural areas is the belief that this group are in poverty and thus largely represents the energy poor. But energy poverty is a problem in every society. This study will help to bridge these gaps in knowledge.

Finally, the decision to adopt a system in a dwelling is a function of so many factors outside the immediate provision of power. To understand this, the rationale behind WTP or the purchase behaviour of households would need to be understood. Purchase behaviour refers to influencers of consumer buying decision. It is simply the motive behind certain purchase decisions that consumers make e.g. choosing to install a roof-top PV. Regarding PV uptake, this purchase decision would be made taking cognizance of vital issues such as household characteristics, space, product quality, efficiency and availability of technical support.

3.6 Coproduction

A less used concept for explaining and addressing the barriers and likely motives for the adoption of low carbon power technologies is coproduction. Coproduction is a very important theory that could help understand the adoption and diffusion issues especially since the provision of public goods has been traditionally the domain of governments. A household's installation of PV, though a personal decision, represents private good as well as a public good because clean power use creates net environmental public benefits (Wiser, 1998). Therefore, PV use can be classified as a public good. However, because it is impossible for the adopting household to solely benefit from their actions (e.g. PV installation), public goods tend to encourage free-riding (Oliver et al, 2011).

Free-riding arises when a non-adopter benefits from the actions of an adopter without having contributed. It is a collective good problem that can be likened to the notion of split incentives[9] often encountered in cooler climates where landlords have to make energy efficiency improvements in buildings rented out to tenants. Simply put, split incentive is a landlord-tenant dilemma with negative effects on energy efficiency

[9] Occurs when building occupants responsible for paying rent (tenants) are different from individuals making improvement to the building (landlord).

measures. It represents unintentional market distortions (Sovacool, 2009) and discourages consumers from investing in energy efficiency efforts.

Growing debates that public infrastructures cannot be carried out by the government alone have seen the increased support for coproduction (Sauter and Watson, 2007). Coproduction is the term used to refer to how individuals in a society can voluntarily play an active part in the production of public goods which can impact them (Ostrom, 1996). A key advantage of coproduction is that it improves the quality of public services and increases social capital (Marschall, 2004). Coproduction further makes for improved citizens welfare especially in developing countries (Mcgranahan, 2015). This means that household uptake of PV can promote public good both from the vantage points of environmental quality and social benefits.

Coproduction has been used to portray options for the delivery of public services for decades. It is also used in studies centred on economic development to advocate coproduction of goods and services (Jakobsen, 2012). A related term sometimes used in place of coproduction is co-provision. It is defined as the voluntary action of citizens in the financing of otherwise publicly funded goods or services or their close substitutes (Sauter and Watson, 2007). Ostrom's (1996) pioneering research demonstrates that under certain conditions, it can be in the consumers' best economic interest to contribute towards public goods.

A more recent study revealed that government support can positively influence coproduction among its citizens (Jakobsen, 2012). Additionally, the study proves that the positive effect was highest on the consumers with the greatest desire for the good; and that the positive outcome only required little governmental effort. It is reasonable to think that citizens who reveal the greatest need for the good may be the well-off in society. However, the participation is not all about the economics of uptake. There are two basic factors necessary for coproduction to properly take effect. The first is the availability of resources. The second is consumer motivation. Participation in coproduction requires that consumers have the resources (ability, time and money) to coproduce. Again, it depends on the level of willingness or motivation and the prevalence of favourable conditions that allow consumer participation (Jakobsen, 2012).

This is where the role of effective governance becomes paramount. Where initiatives that facilitate coproduction exist, equipping citizens with the necessary information and skills will encourage increased participation. Coproduction has been in practice in

Nigeria for decades (Ostrom, 1996). It is accepted as normal for citizens to provide their own means of water supply and power. The key difference is that going by the above definition of coproduction, although the practice is voluntary, it is more of a ‘frustrated response’ by the governed. It arose mainly from the government’s inability to provide reliable amenities for the public. Decades of living in this manner has brought about increased private participation in the provision of traditionally provided public infrastructures and a near total embrace of self-help.

3.7 The notion of Self-Help

Another vital concept that has eluded researchers in this field of study is self-help. This disregard has to do with the fact that basic infrastructural provision is not lacking in advanced economies; hence studies in OECD nations tend to overlook it (Landman and Napier, 2010). Self-help framework can be applied to OECD nations especially as countries look to increase the utilisation of green technologies. For instance, individuals in richer economies who are keen on the impact of climate change can choose to go ahead of the state and single-handedly install residential PV or micro-wind turbines. This can happen when individuals feel that the government is not giving green technologies sufficient attention or where the use of PV subsidies is non-existent.

Resembling coproduction, self-help is a development strategy that involves the participation of individuals in promoting their own good through own assessment of their capacity to bring about positive changes to their living standards and environment (Ibem, 2009). Self-help approaches have featured in development strategies across sectors including housing, and can be aided or unaided (Landman and Napier, 2010). Under the aided model of self-help the state provides a form of support e.g. through part finance or low interest loans to cater for the low-income group. Unaided self-help does not rely on state assistance. Either way promoting self-help is cheaper than full goods or service delivery modes usually deployed by the state. Through self-help the role of government can be been seen to have shifted from infrastructural provision to facilitation of the process of infrastructure provision.

This research investigates the barriers to household PV adoption. It also examines value to households of modern self-generation given certain prevailing conditions. In other words, in addition to examining barriers to uptake, it investigates valuation as a fundamental aspect of attitude and motives to help explain the adoption behaviours. Having discussed the theoretical background of this thesis in this section, chapter four provides an account of the various policy regulations and incentive schemes (including the popular feed-in tariffs-FITs) used to diffuse PV globally.

Chapter 4

4.1 Comparative analysis of country-specific PV support policies and lessons learned

This study specifically examines the barriers to and motives for urban residential PV adoption in Nigeria. To proffer solutions to whatever problems identified, it investigates whether government policy intervention using financial and non-fiscal incentives can increase PV adoption and widespread diffusion. This chapter discusses the role of incentives towards promoting widespread PV innovation diffusion. It does this by examining the various mechanisms and policy tools used by different countries across the globe to promote stand-alone and grid-tied PV systems. The progress made by pioneer countries is explored and the conditions necessary for a successful implementation evaluated.

In studying renewable energy policy it is necessary to distinguish between policy theory and policy analysis, because the latter cannot be properly explained without a good knowledge of the former. Policy theory studies tend to seek answers to why policies are in place in the first place. In contrast, policy analysis studies seek ways to improve the existing policies and processes (Lipp, 2007) by identifying policy successes and failures and their leading causes. In order words, while policy theory concentrates on how micro and macro variables shape the policy process, policy analysis is more concerned about the assessment of policy outcomes (Lipp, 2007). In this chapter, relevant theories will be presented first followed by policy analysis.

For most countries, introducing policies to facilitate the uptake and diffusion of renewables is particularly driven by either the urge for energy security or to lower CO_2 emissions or both (Jäger-Waldau et al, 2011). Countries that lack conventional mineral resources and import most of their petroleum products would be driven to invest in green power technologies. This is done to minimise the risk of scarcity impacting supply and to diversify the energy mix for reduced total costs. Therefore reducing the vulnerability of vital energy systems and environmental sustainability are two key reasons for policy theories in most countries. Policy analysis looks at ways to help administer the policies for optimised benefit. Bearing in mind that there is no one-size-fits-all policy (Fouquet, 2013), this comparative analysis aims to identify best practice for a successful PV promotion.

4.2 Support policies for renewable power technologies

The uptake and diffusion of solar PV or any other electricity from renewable energy sources (RES-E) innovation in many advanced countries is mostly driven by public support policies. While the availability of a resource is the obvious first component of renewable energy investment decision, it does not on its own lead to uptake. The guiding principle is that the concerned country includes the promotion of a renewable power in its list of priorities. Often, countries that include RES-E development as top national priority back it up with appropriate and favourable incentive schemes.

This is mainly the case in richer countries with more mature electricity markets and grid infrastructure. An established electricity market and stable grid becomes increasingly important for purposes of effective grid balancing in situations where privately produced power is fed into the grid network. Examples of leading countries that have successfully used promotion schemes to increase uptake of green power include Germany, Spain and Italy. All three countries utilise the feed-in tariffs (FIT) incentive scheme (Mendonça, 2007) which will be explained in detail in later sections. However, there are debates as to what constitutes a 'favourable' incentive policy (Becker and Fischer, 2013). In this research, it is one that yields the outcome for which the policy was originally designed.

4.2.1 Support policies for solar PV

There are two principal ways for supporting the adoption of modern large renewable power generators such as wind turbines, geothermal, wave and tidal energy and microgeneration technologies such as solar PV and micro-wind turbines. The first involves a mandatory tax on the electricity bills of all consumers. The second involves the voluntary uptake by consumers of such power generation systems like residential PV or by signing up to renewable electricity from network utilities. In the first instance, there is a compulsory increase in the electricity tariffs of all customers and the collected funds are used by the applicable energy company to invest in more green power.

In the second instance, there is a WTP a premium for PV or a voluntary raise in the electricity tariffs of the customers who sign up to renewably-generated electricity. Similar to the initial instance, the funds are reinvested on low-carbon energy systems (Wiser, 2007). Oftentimes, the consumers are influenced by the marketing of such renewable electricity (Rundle-Thiele et al, 2008) or by personal choice. The fact that some individuals can choose or decide to pay for renewable electricity while others do not has been criticised for encouraging free-riding. However, the three major incentive schemes used to promote PV deployment are the feed-in tariffs, Renewable Portfolio Standards (RPS) and net metering.

4.2.2 Feed-in tariffs (FITs)

The feed-in tariffs otherwise referred to as FIT or FITs is a price-based mechanism requiring utility providers to pay PV-power generators a long-term fixed price for electricity generated using their PV (Lipp, 2007; Papadopoulos and Karteris, 2009). An example is rooftop PV owners who feed excess green electricity back to the grid. FIT thus has two elements: the generation component and the consumption component. In a rooftop PV system, the FIT scheme demands that an export/import meter is installed by the adopting households (Keirstead, 2007). This in-home meter helps to coordinate the feeding-in and the buying back from the grid (in the case of net metering) hence cutting energy costs for consumers. As well as reducing expense and risk, FIT also simplifies the adoption of renewables by removing unnecessary complexity that often besets the uptake process of a green power technology.

FIT is legally binding on utilities and obligates them to purchase PV-generated power from generators at a set rate usually guaranteed for long periods. However, where the FIT policy covers diverse sources and technologies the rates offered are differentiated according to a number of attributes of the technologies (Verbruggen and Lauber, 2012). FIT is the most technologically-diverse promotion tool finding application in sources such as geothermal, wind and solar energy (Mendonça, 2007). Denmark started using FITs in the early 1990s and it was central to the highly successful diffusion of wind power in the country (Lipp, 2007). A notable crucial distinction in the FIT policy is determining whether the remuneration rates to be paid to investors are market-based or market independent.

Market-dependent and market-independent FITs

The market-dependent FITs are generally known as premium price policies or feed-in premiums because of the additional payment included to boost the market price. The premiums are designed in recognition of the social and environmental attribute of green electricity or to help estimate the generation costs of other RES-E (Couture and Gagnon, 2010). The market-independent FIT scheme, also known as the fixed-price policies, is the most frequently used and operates outside electricity market prices and inflation by guaranteeing fixed payment for RES-E supplied to the grid (Couture and

Gagnon, 2010). The general FIT tariffs are offered in a relatively fair manner and differentiated depending on the type of green power technology, project location, quality of the resource, installation size and other project considerations. Following such diverse criteria allows for a greater participation of broad investors including large land owners, municipalities, small businesses and households. For the most part, countries that have been successful in using FIT have set their tariff payments as close as possible to the generation costs (Lüthi, 2010). Designing the scheme in such a way ensures that efficiently operated installations remain both functional and cost-effective (Couture and Gagnon, 2010; Fouquet, 2013).

Duration of FIT payments

The duration of the FIT payment agreed is also of immense importance. In Germany FIT was initially fixed for 20 years (Jäger-Waldau et al, 2011; Leepa and Unfried, 2013). The ideal length of support for rapid diffusion is given as 15-20 years (Mendonça, 2007; Lüthi, 2010) Such long-term arrangement leads to certainty on the part of investors that their investment would yield the return given the time frame. A key advantage of the fixed term nature of FIT payments is the security it provides investors. Also by setting the tariff structure on the costs needed to develop a green technology and guaranteeing the payment for a long time the associated risks are minimised (Couture and Gagnon, 2010).

This further makes it easy for a potential self-generator or investor to obtain finance with minimal investment risk and therefore more economically. It consequently leads to a fall in costs of overall module price by raising market confidence not only for the generators or investors, but also for module manufacturers and suppliers (Mendonça, 2007). However, providing an adequate FIT payment to cover investment costs over the lifetime of the project while at the same time ensuring that investors make reasonable profit is a key challenge in using the FIT scheme (Couture and Gagnon, 2010). Added to this is the difficulty arising from making FITs payments for such a long time relying solely on government budgetary allocations.

FIT is widely credited as the most effective instrument for stimulating the rapid diffusion of RES-E (Ayoub and Yuji, 2012) and is currently in use in over 60 jurisdictions worldwide (Couture and Gagnon, 2010; Sun and Nie, 2015). To emphasize, from 1999-2009, 50 countries introduced the FIT scheme globally (Fouquet, 2013). Nevertheless, there are contradictions on the terminologies used to describe support policies as some countries or states use whatever term they consider appropriate to define their scheme (Couture et al, 2015). Many states in Australia use FIT to refer to policies that pay fixed rates for excess produced power as against the usual total production. As one of the leading countries in PV uptake in Africa, Kenya uses FIT but places a price cap under which contracts must be negotiated on a case-by-case arrangement (Couture et al, 2015). The Kenyan FIT programme has been lauded as practical in the view that by limiting the plant size a broader group of generators, investors and users can benefit (del Río, 2012). Regardless of the disagreements or ways by which nations or states choose to interpret the scheme, FIT and RPS are widely accepted, as defined in this study.

4.2.3 Renewable Portfolio Standard (RPS)

RPS is a quantity-based mechanism that obligates utility providers to use a part of their profit to invest in low carbon power sources (Papadopoulos and Karteris, 2009). RPS allows for green certificates to be awarded to green power utility generators for each MWh of electricity generated. As a quota system, RPS is intended to create price competition between RE generators (Lipp, 2007; Rickerson et al, 2007). This allows the market to determine certificate price and compliance; although the government sets the RES-E targets (Fouquet, 2013; Sun and Nie, 2015).

The amassed certificates can later be traded with other utilities participating in the scheme. The reasoning behind the RPS quota system is that a PV generator can receive additional financial benefit from the sales of acquired certificates in the market. In principle, as the number of certificates acquired by participating generators becomes increasingly higher than the stipulated targets, the price drops closer to zero. When this happens further investments in renewables can be made solely on the revenues collected from sales of electricity (Fouquet, 2013).

RPS is the term commonly used in the USA and Canada but is also known as Tradable Green Certificate (TGC) in much of Europe. However, both terms mean the same thing. Notwithstanding the above enumerated schemes, there are discrepancies as to the best policy instruments especially in relation to FIT and RPS. RPS uses numerous adaptations such as banding and capping to regulate the policy but it has not worked out as predicted in theory. RPS was described as more rewarding in situations where the quota is for a specific technology as was demonstrated in a Texas wind power project (Verbruggen and Lauber, 2012).

Another key advantage of RPS is allowing consumers who wish to support green power utilisation to voluntarily purchase renewable electricity from utilities (Wiser, 2007; Amundsen and Nese, 2009). But, the consumers have to trust that the utility company actually generates this power through renewables. This is simply because unlike residential roof-top PV with high visibility, the consumers (i.e. non-PV generators) of central RES-E cannot see the power plants producing the power they are supplied.

4.2.4 Net metering

Net metering can best be described as an extension of FIT but with the added advantage that it allows PV generators to be credited with electricity when their solar panels do not produce sufficient electricity, particularly at night. Net metering is essential where renewable self-generators produce power for their own use and for trade purposes. Net metering allows for the difference between power used onsite by the PV-generator and that sold to grid to be accounted for over a specified period of time. Where the net quantity exchanged with the grid becomes positive, it can be sold back to the grid at retail prices by the self-generator (Klein, et al. 2008). Net metering is designed to reward or compensate green power self-generators for supplying their surplus generated power to the grid (Eid et al, 2014).

Net metering is a low-cost tool for promoting investment in small-scale decentralised generation (DG) (Verbruggen and Lauber, 2012) such as rooftop PV and micro-wind turbines. For net metering to function optimally in grid-integrated systems it makes provision for the use of bi-directional electricity flow meter or export and import meter. It is argued that the retail rates used for net metering are not good enough to spark the growth of less competitive DG technologies such as micro-wind (Verbruggen and Lauber, 2012). As a result net metering schemes are often deployed as supplementary policies in many countries especially in the EU (Dusonchet and Telaretti, 2010).

However, net metering has been found to be hugely instrumental to social welfare as it contributes to reducing the final electricity bills of consumers (Keirstead, 2007; Eid et al, 2014). Net metering has thrived by creating a new type of consumers known as prosumers[10] (Rickerson et al, 2014; Eid et al, 2014). As with other policy schemes, net metering can be used in a number of different ways especially pertaining to metering, accounting and billing of the network user (Hughes and Bell, 2006).

[10] These are self-generators or investors who produce own power for export or for own use from a combination of modern power technologies.

A current chief concern of using net metering is its effect on network operators. Traditionally power networks were designed to function uni-directionally; net metering now constitutes a problem as it makes utilities miss part of their earnings from providing reliable transmission. Hence, Distribution Service Operators (DSO) consider net metering a massive threat to their cost recovery efforts and overall business performance. In consequence higher charges are now applied to PV generators and non-PV generating customers for network usage (Eid et al, 2014). This has been condemned as an unfair practice because such increases to tariffs for all customers leads to cross subsidies[11]. This means that the consumers (non-PV generators) are charged multiple times resulting to inequality amongst ratepayers (Eid et al, 2014).

One way of avoiding such is by applying a self-consumption fee for PV users to incentivize self-consumption and discourage net-production as suggested in Spain back in 2013. The problem with such charges is that it is counter-productive for the goal of getting more people to install PV and for carbon mitigation efforts as a whole (Eid et al, 2014). As a result, the idea of applying self-consumption or back-up fee has received little attention. As at 2010, Belgium, Denmark, Germany, Italy, Portugal and USA were all using net metering (Dusonchet and Telaretti, 2010).

4.2.5 Tendering system

A less common support policy which has begun to gain momentum is the tendering system. Tendering system or renewable electricity auctions is a mechanism that involves a bidding process for power purchase agreements by green power developers. The highly competitive bidding process could also be to access government-administered funds (Mendonça, 2007). Under the auctions system, regulators stipulate the share of cumulative electricity to be attained and the maximum tariff to be paid per kWh. Following this, developers can submit their price bids for contracts (Mendonça, 2007; Couture et al, 2015).Tendering has the merit of encouraging price competition.

Despite the benefits of such systems for developers, by using an auction system, tendering makes for impractical bids as developers bid extremely low prices. The style of competitive bidding also leads to projects being uncompleted (Mendonça, 2007). Other cited disadvantages include that the scheme can prevent smaller businesses from entering the market as by design it tends to favour big players (Couture et al, 2015). Auctions also have the downside of encouraging investments in certain modern

[11] Consumers already subsidize network costs for PV users.

renewables to the neglect of others e.g. large wind turbines become obviously more appealing to utilities and project developers than small biomass (Couture et al, 2015).

4.2.6 Hybrid policy mechanisms

Many countries even in the EU did not meet their previously set RE targets. In a bid to overcome such failures some countries or states have started to combine policies in what is known as policy hybrids. The emergence of hybrid support schemes grew out of a need to tackle the less than expected outcomes many countries have encountered from their attempts to promote green power and RETs. In 2001, France utilised hybrid policy mechanisms for different installation capacity of solar PV by merging FITs and the auctions system. Hence, it is one of the earliest countries to do so (Couture et al, 2015). RES-E policy combinations are considered the future of incentive support (Mints, 2011; Mir-Artigues and del Río, 2014).

What the above serves to reveal is that more and more countries are now moving away from technology-specific support to technology-neutral policies. The UK, for instance uses ‘banding’ as a means of differentiating the generation costs of the various RES-E (Verbruggen and Lauber, 2012). The notion of banding was designed partly to create the impression that some renewable power technologies are not more valuable than others in the policy regimes. Banding is based on the idea that market forces should dictate the prices of the respective technologies so as to enable suppliers to meet their obligation through the most economically viable avenues.

Although on the surface banding as used in the UK appears justifiable and ethical it fails to consider the real possibility of applying such policies given that the disruption levels of the different technologies vary i.e. variable degrees of intermittency and different investment profiles. As a result, some question whether banding or technology-neutral policies would be helpful for the expansion of DGs and for improving the national energy mix (Mendonça, 2007). Others still have branded the quest for technology-neutral policies as illusory in the belief that it is unrealistic in practice (Azar and Sandén, 2011).

Nevertheless, there seems to be a gradual shift also from strictly focusing on costs to other equally vital criteria for successful RE promotion (Couture et al, 2015).By doing so, the energy portfolio in a country becomes increasingly diversified leading to security of supply and overall cost-reduction. This new way of perceiving incentive schemes and grid interconnectivity have created prosumers.

4.2.7 Supplementary policy instruments

Other indirect support instruments used to promote PV are import duty cuts for PV cells, modules and components, sales tax and VAT exemptions and tax credits or rebates. In many advanced societies these support schemes are popular. PV uptake in Africa is largely market-oriented. That is, driven by market forces of demand and supply. Few countries now combine net metering with FITs in ways never before seen bypassing the traditional definition of both and adapting the schemes to suit their national objectives and policy priorities. Such practices are predominant in the Caribbean and Pacific Islands region (Couture et al, 2015). The above detailed forms of policy support have ensured steady maturation in the PV market of countries such as Italy, Spain, Japan and Germany. Using the innovation diffusion curve Figure 4.1 shows the outstanding German and Japanese PV market development over time.

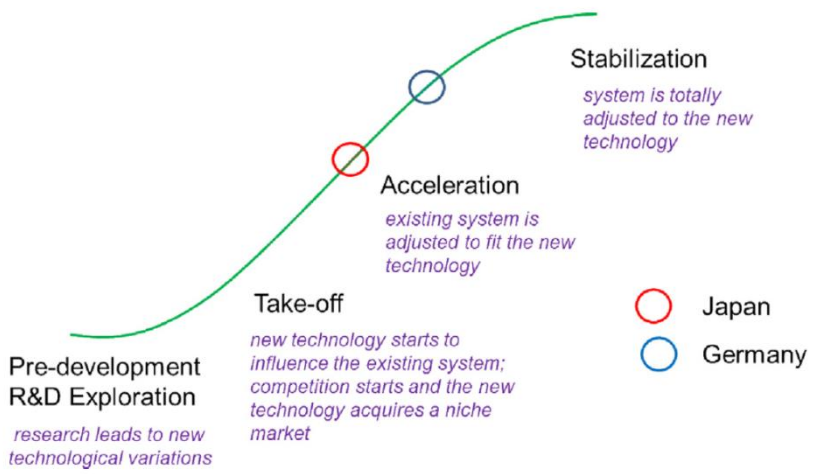

Figure 4.1 Position of Germany and Japan on the PV innovation diffusion curve

Source: Chowdhury et al, 2014.

4.2.8 FITS versus RPS

Much of the disagreement on which mechanism to deploy is to do with the role of government in supporting green power (Lipp, 2007). RPS has been criticised for hampering investment in renewables due to the high level of uncertainty attached to the future value of the tradable green certificates (Mir-Artigues and del Río, 2014). Where prices are not fixed or guaranteed there is the tendency for investors to be wary of future energy prices and its impact on their capital investment. Quite reasonably, investors want to know what they will receive in repayments, but because RPS certificates are tied to fluctuating market prices investors cannot be given definite future value (Mendonça, 2007). Hence, compared to FITs, RPS does not ensure market stability for investors (Lipp, 2007). Such uncertainty is linked to costly risk premiums making investment costs far too expensive (Mendonça, 2007). Such uncertainties negatively impact the diffusion of green power technologies.

Another criticism levelled against RPS proponents is that by offering a single price for each technology it is only reasonable for investors to opt for the cheapest green technology. This would mean that other sustainable technologies with great potential are ignored thereby suppressing markets. By encouraging investors to choose least cost RPS policies leads to development in concentrated locations (Lipp, 2007) e.g. wind power development in Scotland. This further pushes smaller competitors out of market (Mendonça, 2007). Unlike RPS, FITs, it is argued, takes cognizance of the different stages of development of various RES-E technologies and their disparate generation costs (Lipp, 2007). The differences in payment tariffs further encourage the development of green power in diverse locations (Menanteau et al, 2003).

Finally, in terms of gaining market volume or installed capacity, FITs is considered the best policy tool to apply. It is seen as useful for stimulating industrial capacity and employment creation (Lipp, 2007; Sun and Nie, 2015). But if the goal is to significantly reduce carbon emissions, RPS was recently shown by Sun and Nie (2015) as the most beneficial policy mechanism to deploy. In relation to cost control, and dynamic efficiency[12] (used to evaluate the success of RES-E support scheme), RPS was considered more advantageous than FITs (Sun and Nie, 2015). Again, the decision is often made based on national priorities, policy goals and perceived cost effectiveness.

4.3 Global pioneer PV countries

Germany

FITs have been in use since the late 1970s but on a low scale. During this time, PV systems installation was largely demonstration projects for remote applications due to lack of subsidies (Mints, 2011). In any case, FIT was first applied by the US Public Utilities Regulatory Policies Act (PURPA) in 1978 (Lipp, 2007; Mendonça, et al, 2009). Then the scheme guaranteed rates based on the long term projected costs of fossil fuels. It was later abandoned following the deregulation exercise of the US

[12] Dynamic efficiency is the capacity of a design tool to bring about continuous incentive for technological improvements and cost reduction in existing and emerging green power technologies (del Río, 2012).

electricity markets (Lipp, 2007). Germany introduced FIT in 1991 under the 100,000 roofs initiative (Lüthi, 2010) using very low tariffs (Chowdhury et al, 2014) which were increased over time. In 2000, the Erneuerbare-Energien-Gesetz (EEG) or Renewable Energy sources Act was introduced. Later in 2004 the EEG was amended greatly amplifying the existing FIT structure for 20 years (Jäger-Waldau et al, 2011).

As part of the FITs law, the tariff structure was designed to be reviewed year-on-year due to scale economies (Lipp, 2007). This review was also part of the declining payments structure to the different technologies. Using the principle of shared burden (Lüthi, 2010) costs were spread equally amongst consumers to reduce the cost burden on general electricity end-users who then paid roughly £1 extra per month (Mendonça, 2007). The EEG included an element that reduced FIT annually. Up until early 2012, FIT payments were cut by 3% yearly and an additional 3% for each GWp that exceeded the governments stipulated targets (Leepa and Unfried, 2013). In addition, the policy allowed for system sizes of any capacity to be included knowing that the grid capacity could cope with it. This approach ensured that a wide range of consumers including small businesses, farm owners and households could take part (Dinçer, 2011).

In consequence, as at May 2015 the German PV industry had installed capacity of over 34GW (PV Magazine, 2015) and a flourishing PV industry. As at end 2014, Germany held the highest PV capacity per capita (REN21, 2015).This notwithstanding, wind power represented the bulk of total RES-E generation in Germany at 7.4% with PV standing at 4.5% in 2012 (Kirsten, 2014). Although the German FIT scheme is widely acclaimed to be a success not everyone agrees. Researchers Frondel et al, (2010) argued that it failed to administer a cost-effective integration of RES into the country's energy mix. Hence, they called for an abrupt cut in the FIT payments for PV, arguing that it may be negatively impacting employment (Frondel et al, 2008).

Spain

As mentioned previously Spain is one of the largest PV markets in Europe despite starting from a very small base (González, 2008). Spain is an interesting case because it was a big importer of energy products up to mid-2005 when the government gave its approval for the renewable energy plan act 2005-2010 (Dinçer, 2011). The case of Spain is even more intriguing given that as a Mediterranean country it has an excellent solar resource compared to many EU countries (Lüthi, 2010). The German FITs success inspired both Spain to promote PV as unlike Germany it benefits from higher solar radiation (1200-1800kWh/m^2/year) (Dinçer, 2011).

Until September 2008, Spain made use of the legal framework-Real Decreto (Royal Decree) 436/2004. The scheme allowed investors to choose between exporting the generated power using fixed-FITs or selling in the open market where they can benefit from changing electricity prices (Dusonchet and Telaretti, 2010). PV diffusion and capacity is primarily promoted through the use of solar farms or solar parks (mostly >10 MW systems) including tracking systems (Dusonchet and Telaretti, 2010). The legal framework was revised in 2008 and later again in 2010. The aim of the 2010 decrees limit the duration of FITs to 28 years and to reduce the rates by 10% and 30% until 2014 (Jäger-Waldau et al, 2011).

The PV market in Spain is billed to grow immensely in the coming years with some predicting it would surpass Germany. There are plentiful signs as to why this would happen. Recent years have seen increased investment in PV with Spain becoming the first EU country to install a commercial-scale concentrating solar power (CSP) in Seville, in 2007 (Dinçer, 2011). In the course of its PV development Spain utilised generous FITs as a means to register similar growth path as Germany even setting its payment for 20 years+ (Lüthi, 2010). However, the FITs were given for an uncertain number of years with a reduction after 25 years (Dusonchet and Telaretti, 2010).

With such rates and guarantee, it would be expected that Spain's PV market would perform better than that of Germany. Results indicate otherwise. What was found was that a more critical factor to a successful design was reducing policy risk rather than an uncontrolled desire to ensure Return on Investment-ROI. In other words, there exists a higher correlation between policy risk and PV uptake than there is with ROI and PV uptake (Lüthi, 2010; Mir-Artigues and del Río, 2014). Therefore, not providing potential investors with clear FITs schedule leads to sensitivity to future policy costs and unwillingness to participate.

As with Germany, the FIT cap was also shown to have affected the PV diffusion in Spain. In 2007 the cut-off cap was set at 371MW (Lüthi, 2010), 500MW in 2009 (Dinçer, 2011) and 400MW in 2010 (Dusonchet and Telaretti, 2010). This led to a fall in investments in subsequent years to 2011. Although it is still considered by many as an example of a successful FIT policy regime, some still see the period as a boom and bust era for Spain (Mir-Artigues and del Río, 2014). Later years saw a more rewarding and cost-effective FITs regime. As was the case with the German experience, the two key factors that led to Spain's success were widespread socio-political support leading to government commitment and the ensuing steadiness of its support schemes.

Italy

Like Spain, Italy enjoys a good solar resource. The Italian government supports PV using mainly FITs and net metering. Its FITs scheme is exclusive to PV as it utilises TGC for other RES-E (Dusonchet and Telaretti, 2010). Like Germany, Italy has a differentiated promotion system for its RES-E (de Río and Mir-Artigues, 2012). In 2010, Italy was the second leading country in PV installations addition and was amongst the top five leading countries with respect to cumulative PV capacity (REN21, 2011). The fast growth of its PV industry meant that in 2010, the installed capacity was >3.4GW (REN21, 2011; Jäger-Waldau, 2011). Hence, along with Germany and Spain, Italy is considered one of the most successful PV markets (del Río, 2012). There is even increased investment in other PV technologies such as concentrating PV (CPV) and concentrating solar thermal power (CSP) (REN21, 2011).

According to Gestore Servizi Energetici (GSE, 2014) the state owned company with the responsibility to promote and support RES, Italy uses FIT as an incentive for generators supplying power to the grid. It was originally introduced in 2005 via a ministerial decree and was referred to as the 1st feed-in scheme. Although the 5th feed-in scheme was instituted; it was withdrawn on July 6th, 2013 after set cap of €6.7b per annum were exhausted. The most current support is the 4th feed-in scheme which is intended to last until end 2016. Grid-tied system sizes of 1kW and greater are eligible and is guaranteed for 20 years. It only applies to installations done within 1st June 2011 to 31st December 2016 (GSE, 2014).

Additionally, Italy is one of the foremost users of TGCs in Europe introducing it in 2001. It grants very high rates for its certificates compared to Sweden and the UK but has modest quota fulfilment (Haas et al, 2011). These researchers also argue that similar to Belgium, Italy's TGC has faced the lowest deployment despite its high tariffs. TGC has been shown to have far higher revenue risks in comparison to FITs (Mir-Artigues and del Río, 2014). However an observable trend in PV deployment in the EU as a whole is a shift towards utility-scale PV installations (REN21, 2011).

France

As a country reliant on nuclear power for 75% of its electricity supply (BBC, 2014; BP Statistical Review, 2015) France is looking to move to modern renewables. The Ministry for Industry Decrees instituted in 2006 is the legal framework for PV incentives in France (Dusonchet and Telaretti, 2010). FIT is the primary mechanism used to promote RES-E. France uses term-based FIT adjustment mechanisms where FITs for PV is adjusted by 2% every year as against the current chiefly capacity-oriented mechanism of Germany (Leepa and Unfried, 2013). As a control, the government adjusts its FIT payment by tracking inflation rates. Similar to Italy it differentiates the rates used to promote RES-E (Couture et al, 2015).

Due to a good FIT tariff, in 2010 its total PV capacity reached 1GW (Jäger-Waldau,et al, 2011) and at the beginning of 2014 it had exceeded 4.8GW of PV installation (PV Magazine, 2014). France's effective FIT regime has incentivized a large group of consumers (including couples, general households, schools and the health sector) (Dusonchet and Telaretti, 2010) to adopt PV. The rapid PV expansion even led to a cap in 2012 of 800MW after which the provision of FITs would cease (Jäger-Waldau,et al, 2011). However, the regulatory and administrative hurdles such as the delay in issuing permits and access to grid have restricted growth (Dusonchet and Telaretti, 2010).

One key distinction between France and other EU countries is its unrivalled focus on promoting building integrated PV (BIPV). Its PV market is predominantly BIPV for the domestic and commercial sectors (Dusonchet and Telaretti, 2010). This it does by providing support for both roof-mounted PV and wall-mounted PV (REN21, 2011). BIPV is a fast growing technology and a chief driver of the market diffusion of PV (Jäger-Waldau et al, 2011). Depending on type and size of technology the tariff for 2011/2012 ranged from €0.28 to €0.46/kWh for systems of 1kWp to 100kWp; and €0.12/kWh for 100kWp to 12MW PV sizes (Jäger-Waldau et al, 2011).

Another unique strategy used by France to support PV is hybrid policy which it introduced in 2001. Under the France hybrid design, FITs were instituted to stimulate investments in smaller (<100 kW) green power installations while auctions were used to drive investment in large installations (> 1MW) (Couture et al, 2015). Taiwan deployed such coalition or fusion policy in 2011 using the same schemes as France but for different system sizes. Due to the layering structure of its hybrid mechanisms, France experienced a far greater success than Taiwan (Couture et al, 2015). However, combining tariffs is not a guarantee for success. Artigues and del Río (2014) found that when FIT was combined with investment subsidies and soft loans, the policy costs were identical with the FITs-only alternative, hence no difference. Which means combining tariff is not an end in itself.

UK

In the UK the promotion of RES-E is done under the framework - the Microgeneration Strategy first launched in 2006 (Dusonchet and Telaretti, 2010) and later revised in 2011 under the coalition government. The aim of the microgeneration strategy was to address issues related to non-financial hindrances to uptake by ensuring that quality devices and installations are carried out for investors (Balcombe et al, 2013). The major regulatory policy used in the UK is RPS which it refers to as Renewables Obligation (RO). The use of RPS is particularly to stimulate large-scale PV deployment. OVO energy and Ecotricity are examples of utilities utilising RPS to supply green electricity to end-users in the UK. The UK refers to the traded RPS certificate as the Renewables Obligation Certificates (ROCs) (OFGEM, 2014). The UK ROC rates are dependent on market forces and set targets (Dusonchet and Telaretti, 2010).

Another scheme introduced in 2010 is the Renewable Heat Incentive (RHI) (REN21, 2011). FIT was also introduced in 2010 and used to promote MGTs such as residential PV. The support for MGTs led to over 320,000 PV installations as at 2012 (Balcombe et al, 2013). While the UK PV market has been growing albeit slowly recent sudden cuts in tariff is threating the development of the industry (Mints, 2011). Pre April 2012, the FITs tariff for PV was £0.43/kWh. After this time it was reduced to £0.21/kWh (BBC News, 2012). In the subsequent months, general UK PV installations stalled. This problem was not only observed in household installations but also in commercial-scale installations with a recent drop of the tariffs (Energy World Magazine, 2014).Under a new plan the subsidies for small-scale PV will be completely phased out (BBC, News, 2015) further worsening the situation.

Japan

Japan is a big importer of petroleum products due to the shortage of in-country fossil-based energy resources (Dinçer, 2011). This has meant that since the 1970s Japan has sought to include renewables in their energy portfolio. The Sunshine Program introduced and revised between 1974 and 1981 was the foremost initiative aimed at including solar energy in its power generation (Chowdhury et al, 2014). However, the first legal framework used to stimulate the deployment of PV was the Monitoring Program for Residential PV systems introduced in 1994 and lasted until 1996. This scheme made use of very generous federal subsidies to the tune of 50% support (Shum and Watanabe, 2009) to accelerate growth. Subsequent years saw increased policy support as can be observed in Fig 4.2 below. Japan's aim was to create a PV market using short (subsidy, taxation, grants) and long-term (FITs and Quota system) support (Ayoub and Yuji, 2012).

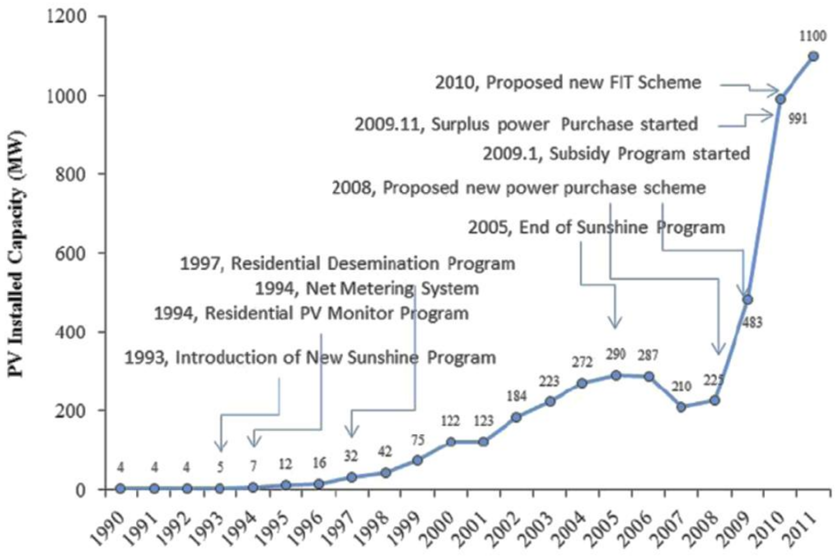

Figure 4.2 PV market growth in Japan from 1990-2011.

Source: Chowdhury et al, 2014.

Japan has invested heavily in solar PV bringing about a boom in the industry especially in the early 2000s. In terms of cell and module manufacturing it has the globe's largest independent PV industry (Dinçer, 2011). Japan takes advantage of its housebuilding sector which builds large volumes of fixed-design buildings each year to promote PV (Shum and Watanabe, 2007; Dinçer, 2011). PV is treated as a manufactured technology by standardising the modules and minimising opportunity for customisation. This is done to record immense PV uptake and consequently market diffusion (Shum and Watanabe, 2007; 2009). Because it builds over 10,000 homes each year, its design targets the residential sector. The residential PV sector accounted for over half of total installation in Japan during this period with 90% grid-tied (Shum and Watanabe, 2007). Having been declared as successful the PV market was left to self-support (Shum and Watanabe, 2009; Chowdhury et al, 2014).

It is thought that the consumer awareness created early on, the presence of stable incentives, FITs and the use of mass-production principle as against the user-centred customisation model applied in the USA, is the reason for the effectiveness of its schemes (Shum and Watanabe, 2007). However, the cessation of the support scheme in 2005 affected its market diffusion. Despite Japan registering greater growth than Germany in the first half of the year commencing 2000 (Shum and Watanabe 2007), Germany later surpassed Japan in PV diffusion and general market development (Choudhury et al, 2014). However, Japan took third place in 2010 for world ranking of installed PV capacity (REN21, 2011). The cumulative installed PV capacity increase from 4.9GW in 2011 to 23GW in 2014 (BBC News, 2015) is evidence of this positive trend.

USA

The United States of America is one of the most RES-E policy-diverse countries in the world with different states enacting support schemes as deemed fit. The incentives are based on technology type and size. The USA is widely regarded as a forerunner in the use of RPS for PV promotion (Rickerson et al, 2007; 2008). Other policy instruments used are net metering, grants, income tax credits and rebates (Jung and Tyner, 2014; Darghouth et al, 2014). The USA also use a combination of incentives to promote residential and commercial PV with most of the installations grid-connected (Sarzynski et al, 2012).States such as California, Texas, Arizona and New Jersey are renowned for their solar PV and solar thermal utilisation (Krasko and Doris, 2013; Haley and Schuler, 2011) with grid-parity already achieved in some locations (Jung and Tyner, 2014).

While the USA has historically relied upon RPS, in 2008 six states introduced the FIT scheme with other states joining in afterwards (Rickerson et al, 2008). The Database of State Incentives for Renewable Energy (DSIRE) is used to record RES-E adoption date but excludes installations that have expired (Sarzynski et al, 2012). USA is one of the largest PV markets in the world. However, it has been criticised for a narrow and unstable regulatory policy which has led to complexity and doubts amongst potential investors (Haley and Schuler, 2011).

China

Along with Taiwan and South Korea, China is one of the largest PV markets and has some of the world's top PV module manufacturing industries e.g. Trina and Yingli (REN21, 2015). The rapid growth in the PV market in the last 10 years in these countries has led to a significant drop in PV prices globally with overcapacity leading to some investors leaving the industry in the last few years. Notwithstanding this, as at end

2014, China was the second largest PV power producing country in the world (REN21, 2015). Table 4.1 is a summary of selected leading countries, their key support schemes and supplementary support instruments.

Table 4.1 Summary of PV support schemes in leading countries

Country	FITs	RPS/ TGC	Net metering	Tendering (bidding)	Capital subsidy, grant, rebate	VAT/sales cuts & tax/RE credits	Loans	Admin	Funding source	Total installed size (2014) GW	Duration (Years)
Australia	RR*	x	x	●	x	x	x	SD	Ratepayers*	4.1	20 (SD)
China	RR*	x		x	x		x	RD/N	Combination	28.2	25
France	x			x		x		N	Ratepayers	5.7	15-20
Germany	RR*		x		x	x	x	N	Ratepayers	38.2	15-20
India	x	x	x*	x	x	x		RD/N	Developers	3.2	25
Italy	S*	x	x		x	x		N	Ratepayers	18.5	15-20
Japan	RR*	x			S*			N	Ratepayers	23.3	20
Kenya	x	x		x		x		N	Ratepayers	10MW	20
South Africa	x	x		●	RR*	RR*	x	N	Developers*	0.9	25
South Korea	C*	x	x		x		x	N	Budget	2.4	5+Repairs
Spain	S*		x			x		N	Ratepayers	5.4	20-30
UK	x	x			x	x		N	Combination	5.2	20-25
USA	x	x	x		x	x		SD	Combination	18.3	10-20 (SD)

Support policy symbols: RR* imply scheme was recently reviewed; x implies scheme is in use; S* suspended; C* ceased; ● newly introduced;

Programme administration symbols: SD implies state differentiated; RD region differentiated; and N imply national.

Funding source: Ratepayers (*) imply recently introduced; Developers (*) means recently introduced.

Table created by author using data from multiple sources including REN21, 2015; Burtt and Dargusch, 2015; Choudhury et al, 2014; Nganga et al, 2013; Becker and Fischer, 2013; del Río and Mir-Artigues, 2012; Ayoub and Yuji, 2012; Haas et al ,2011; Haley and Schuler, 2011; and Dusonchet and Telaretti, 2010

Kenya

Kenya is regarded as the African equivalent of Germany's PV success story (Ondraczek, 2013). From a very small beginning in the early 1990s (Gope et al, 1997; Jacobson, 2007), the Kenyan PV industry is now one of the largest in Africa after South Africa. It is also amongst the top 20 PV markets in the world (REN21, 2015)**.** Earlier development was from cash purchases and later donor-funding (Jacobson, 2007). This donor-led approach is still common with developing countries even in Asia (Sovacool et al, 2011).

Kenya currently uses FITs to promote PV uptake for increased capacity. Kenya's national off-grid solar installed capacity has thus increased from 5MW just a few years ago (Kassenga, 2008) to an estimated 10MW in 2012 (Ondraczek, 2013). Some argue that a contributory factor to Kenya's solar industry is the absence of oil and natural gas deposits and the geographically dispersed nature of the country making grid networks unviable (Kassenga, 2008). The country depends largely on hydropower and the importation of petroleum products. Its hydropower facility frequently suffers from droughts making modern renewables feasible. Yet, it is clear that Kenya's remarkable solar energy market grew from a relatively modest start.

Although a larger proportion of the solar home systems (SHS) purchased by these rural households are small systems (mainly <100 W) (Jacobson, 2007), Kenya now has over 320,000 SHS (Ondraczek, 2013). The country also boasts substantial manufacturing and distribution outlets for SHS systems from the experiences gained (Ondraczek, 2013). Later solar sales in Kenya were stimulated by the government's policies through removal of import duties from 1986 to 1991, and again from 2000 to 2002 (Bawakyillenuo, 2012). Kenya's experience with PV for off-grid and on-grid generation is worth learning from. It can serve as best practice in the African context of PV usage and promotion. Figure 4.3 shows the countries in Africa presently using FITs for PV.

Figure 4.3 Map of Africa showing countries currently using the FIT policy. Data collected from multiple publications[13].

KEY

▲ = FIT policy in process of development

▲ = FIT policy in use

Nigeria

PV adoption in unsubsidized markets like Nigeria is primarily self-funded. The intention to use FIT was announced as part of the Renewable Energy Master Plan and vision 20:2020 agenda of 2010 (ESMAP, 2013). The FIT is under development and PV uptake is still largely market-driven. Though this seems to be a common trend in Africa,

[13] Information obtained from REN21, (2015); Nganga et al, (2013) and PV Magazine, (2013).

the total absence of incentives or low presence of stimulating mechanisms is often related to the stage of socio-economic development. But this lack of fiscal and non-fiscal support hinders PV uptake and diffusion.

The deployment situation in Nigeria means that individuals have to pay the full amount of the PV device in order to install them for power supply to their homes. Considering the high upfront costs this stands as a deterrent for most people. This may be the reason why PV growth has been very slow in Nigeria despite interests shown since the 1980s. Relying solely on cash-mode or plug and play (Sauter and Watson, 2007) approach to PV uptake in Nigeria will not develop the PV industry as countries like Kenya, and Tanzania have demonstrated.

4.4 Specific outcomes and lessons learned

Evidence suggests that the generally successful German FIT model was to do with a combination of factors. After the early 2000s the German FIT took off due to the liberal incentives (Dinçer, 2011), uninterrupted FIT rates over the long term and meticulous policy planning (Lipp, 2007; Lüthi, 2010). The FIT scheme was made clear from the onset and benefited from sustained support (Mendonça, 2007). Most importantly, the PV policy in Germany made use of a sort of hybrid policy (Kirsten, 2014). This can be seen in the use of both FIT and low-cost loans earlier on at the introduction and early growth phases (1998-2004) to aid development of the PV industry. The use of FIT payments alone would have been insufficient to trigger the required market diffusion (Lüthi, 2010).

Researchers have further pointed to the importance of the source of funding for FITs scheme. It is thought that financing FITs using charges applied to all electricity customers as was done in Germany is a more rewarding approach than resorting to government budgets only (Mendonça, 2007; Lüthi, 2010). This would mean that the payments are likely to continue over the longer term. Therefore, it becomes less difficult to sustain FITs through this medium and when continuity is ensured customers can invest confidently. The German FIT programme in the early 2000s also thrived despite three government regime changes (Lipp, 2007); further pointing to the essential importance of policy continuity.

In addition, if due to budget constraints high FITs payments cannot be guaranteed over the long term, small but sustained payments should be resorted to (Lüthi, 2010). Therefore, small reliable payments are better than generous short-term FITs which oftentimes are ineffective due to the inconsistent payment pattern. Argentina is a good example of a country that has shown the possibility of using low tariffs (€0.37/kWh) to support renewables. Its sustained scheme made it possible to have a stable 30MW of wind capacity (del Río, 2012). Finally, it is thought that the oil crisis of the 1970s, the Chernobyl nuclear disaster of 1986 combined with the worrying concern about climate change all led to Germany's switch to renewables (Lipp, 2007). Aside the EU 20-20-20 carbon reduction binding target the German government's decision in 2011 to phase-out nuclear power by 2022 was a driving factor (Sühlsen and Hisschemöller, 2014). Japan's Fukushima nuclear power meltdown of 2011 undeniably added to this drive.

Taiwan's experience with combining tariffs for PV revealed that more than granting munificent tariff rates, the presence of a supportive bank lending system for debt financing and ensuring that the costs of RES-E generation are accounted for over the long term are equally vital (Lüthi, 2010; Couture et al, 2015). As demonstrated in France, other important issues such as the ease of issuing permits and general administration of the policy should be carefully considered. While ROI factors is sine qua non to investors there is need to look beyond this and concentrate more on risk-based factors i.e. ensuring policy stability and a careful use of FIT caps (Lüthi, 2010; Leepa and Unfried, 2013).

There are a number of downsides to the use of caps to signal a threshold has been reached and therefore FIT payments can no longer be continued. First, a long time before the stated cap value is reached there is uncertainty among investors. The potential investors would be unsure if their RES-E project would yield return on investment (ROI) before the government specified cap is attained. Secondly, since post-cap conditions are not often specified by policy initiators the potential investors may assume that policy-makers will make new rules to support PV which may impact them (Leepa and Unfried, 2013). Thirdly, caps lead to hesitation and hinder PV diffusion as unexpected policy changes are huge risks most potential investors are reasonably unwilling to take (Lüthi, 2010).

Conversely, caps can result in a rush to install before the cap end-date leading to overinvestment as shown in Germany and Australia (Leepa and Unfried, 2013; Macintosh and Wilkinson, 2011). See also Mints (2011) for this consumer behaviour change. It is rational from an investor's point of view as investors need to act before the window of opportunity closes. Figure 4.4 is evidence of what happened in Germany in the last month to the FIT cut-off date from 2009-2011. The diagram is an illustration of the effects of cap on FIT payments in Germany for newly installed PV. The dotted lines indicate cut-off dates for the FIT payment scheme. The overwhelming rise in demand goes to depict investor response to FIT caps.

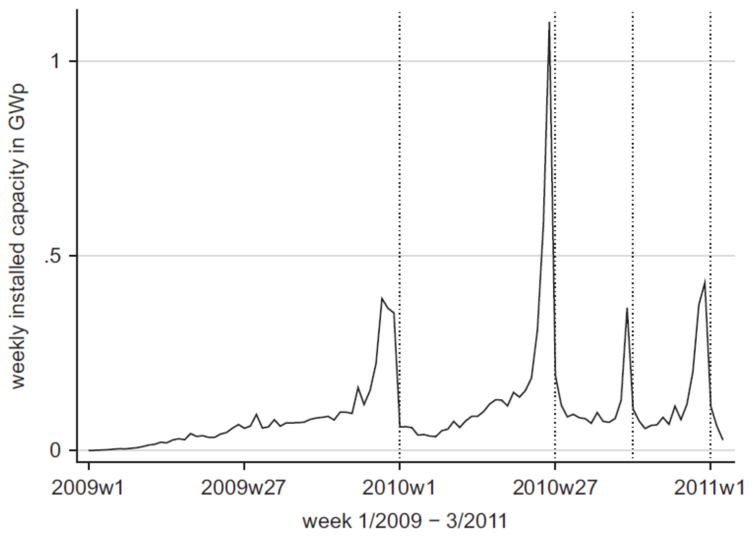

Figure 4.4 PV Investor response to FIT caps in Germany from 2009-2011.

Source: Leepa and Unfried, (2013).

Such changes increases cost burden to the wider non-PV adopting consumers as was recently experienced in Germany. Thus, in order to control this problem, since 2010 FITs was scheduled for quarterly/yearly reductions based on installed capacity (Jäger-Waldau, 2011; Leepa and Unfried, 2013). This does not mean that caps or ceilings are not useful support mechanisms or that they should be completely scrapped which is actually impossible. The reason is that capping FIT is a way to regulate the FIT policy. Nonetheless using such measures should be carefully thought out and executed to minimise investor fears.

Furthermore, the performance of Greece and Spain in the first decade of the century is evidence of market stagnation that occur from such omission (Lüthi, 2010). Lessons from France further show that there is a strong case for introducing and keeping FIT schemes for small PV installations to encourage small families and individuals to participate. Couture et al (2015) found that decisions such as removing entry barriers to a diverse group of investors led to a substantial rise in PV uptake and widespread diffusion. The layering structure of simple and complex FITs used by France for the different project sizes as depicted in Figure 4.5 was a key reason for its success. France's impressive strategy takes into cognizance the crucial role of small adopters towards advancing PV technology.

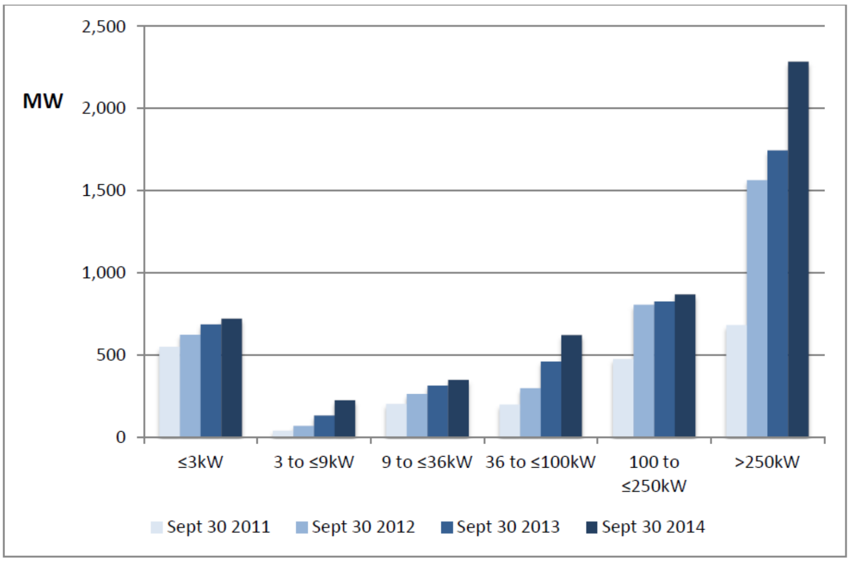

Figure 4.5 The breakdown of solar PV capacity in mainland France from 2011-2014

Source: Couture et al, (2015)

4.5 Summary of comparative policy analysis

Despite the above recorded success in some European countries, Japan and the USA there are dissimilarities as to the efforts being made towards energy efficiency globally (Jäger-Waldau, 2007). This is evident between advanced countries. The differences can also be observed within continent or region e.g. the European PV market. For instance, Germany and Denmark stand out in solar PV and wind turbine power installed capacity and are generally perceived as frontrunners in the use and promotion of green power technologies.

The disparity in the efforts made towards promoting PV comes from the fact that market situations vary across countries. In addition, nations have different cultures and histories and this impacts policy decisions (Lipp, 2007). Also, political set-up (Fouquet, 2010) and the stage of development of electricity market deregulation or liberalisation affects the efforts directed at energy efficiency measures such as PV adoption (Jäger-Waldau et al, 2011). A combination of these factors adds to uncertainty.

Public policy-makers cannot fully ascertain certain things due to bounded rationality or limited knowledge. For instance, metrics such as inflation and fuel prices can change without warning. The existence of such uncertainties would mean that it is unwise to channel resources to a small set of green power technologies. Focusing on a small selection of RES-E not only signals a preference for the selected few it can also lead to ‘cherry-picking’ of the emergent technology too early in its development (Bolton and Foxon, 2015).

Of particular importance in this comparative analysis are the lessons learned from successful countries which include taking cognisance of falling module prices in setting tariff structure. Carefully thinking through FIT design and applying digressive rates. Using effective ceiling measures to manage PV investments. Lastly, the efficient use of front-loading[14] as a strategy for sustaining FIT payments over time is also important as exemplified by most countries examined in this review.

Having reviewed the schemes used to support PV and RES-E in this chapter, the following chapter discusses the research methodology, approaches and analysis techniques applied in this research.

[14] Using higher FIT rates at the initial stages of support and lowering the rates at latter stages as technology improves (Couture and Gagnon, 2010).

Chapter 5

5.1 Methodology

In this chapter, details of the systematic procedures and methodical frameworks used to carry out the study are presented. The chapter includes processes such as; research philosophy, research techniques adopted, the study design, location, respondent recruitment approach and data collection and analysis strategies. The justification for the choices made at each point are sometimes stated implicitly and at other times described separately as deemed necessary.

This study questions the role PV can play towards improving electricity use in Nigeria by investigating the barriers to and motives for PV uptake. It also explores the likelihood of government support to positively influence PV adoption and widespread diffusion. The study further investigates the potential of PV towards bringing about greater energy use efficiency. In order to achieve these goals, this study employs the use of mixed methods. This is because to examine such a research problem where both hindrances and motives are sought, the approach that would reveal the most useful results would be one that caters for the twin nature of the hypothesis.

To meaningfully gather data on such information would require not only strategies that yield numerical data as to the hindrances to PV uptake, but also those that help gain deeper insights into the motives of the few PV adopting households. Therefore the use of mixed methods was considered a more effective approach. The first research problem (mainly barriers and WTP) was investigated following a quantitative method while the second research problem (motives) was qualitative and used interviews. It is intended that the findings from both methods and the comparative policy chapter will be used to create a practical tool for encouraging household-level PV adoption in Nigeria. In the following section, the research methods and other techniques employed in the research will be described and the reasons behind the decisions made will be given in subsequent sections. First, the research philosophies underpinning study will be briefly introduced.

5.1.1 Research Strategy: Quantitative research methods

In this section, the quantitative techniques employed will be explained. It is quite common to see publications in energy-related research where the differences between quantitative and qualitative methods are not explicitly shown. Most such studies only report that they made use of questionnaires or interviews as the case may be. There is a distinction all the same.

In general terms, quantitative methods are those that seek to obtain numerical data through surveys. A key goal of conducting a survey is to use quantifiable results to relate to opinions and attitudes (Borrego et al, 2009). But quantitative methods are much more than generating numbers (Bryman, 2012) as will be demonstrated in this study. A quantitative research method is one that uses theory or hypothesis to justify the variables, research goals, and the direction of the clearly defined research questions (Borrego et al, 2009). It has pragmatic beginnings and employs deductive reasoning to explain social facts related to human behaviour. It seeks out distinct features or characteristics and measures *how much* and/or *how frequently* a given phenomenon occurs (Borrego et al, 2009; Amaratunga et al, 2002). Aside the desire to gather numerical data from the questionnaire to aid replication and possible generalisation, other reasons for using quantitative methods are:

- Participants views can be measured objectively without interference
- To allow the measurement of descriptive statistics
- To simplify large datasets by reducing them to aid analysis; and
- Because reliability and validity can be confirmed objectively.

However, quantitative methods are not without criticism. A major criticism is that because of its ‘snapshot’ approach (Amaratunga et al, 2002) it fails to capture deeper underlying meanings that participants tend to convey in surveys. It is partly for this reason that interviews were later employed in the second part of this study to gain in-depth and richer understanding of the factors impacting PV adoption.

5.2. Household questionnaires

The survey research method used in this study was a questionnaire. Questionnaire surveys allow for detailed comparisons between related variables by identifying relationships and differences in a positive way (De Vaus, 2002). Such surveys are flexible in data treatment through their use of statistical inference and comparative analysis. The fact that data from quantitative research can be used with varied statistical analysis tools is one of its many benefits. This explains its acceptance and widespread use for examining the behavioural aspect of the built environment (Amaratunga et al, 2002).

Many studies have examined off-grid renewable energy promotion through quantitative research methods (Leenheer et al, 2011; Sardianou and Genoudi, 2013). Studies in innovation diffusion and willingness to pay for PV and renewable electricity have also successfully applied quantitative methods (Claudy et al, 2011; Yuan and Ma, 2011; Komatsu et al, 2013; Soon and Ahmad, 2015). In addition, mixed methods have previously been used to elicit households' views on the hindrances to and motives for green power adoption (Keirstead, 2007; Soon and Ahmad, 2015).

5.2.1 Location, sampling and rationale

Having established the household sector as a dominant one in total energy demand in Nigeria (see Chapter 2, Section 2.3), the questionnaire targeted urban households. Lagos State was specifically chosen as the study location for the questionnaire survey. The city has one of the largest populations (over 20 million) of any state in Nigeria. It was the former federal capital with leading infrastructural developments. It is the industrial and commercial centre of Nigeria with about 60% of total industrial investments and foreign trade taking place in this coastal city. It also has the largest ports in Nigeria facilitating imports and exports of goods and services.

As a central location, this metropolitan city is responsible for 35% of national GDP. There is increasing interest in green energy development too (Lagos State Government, 2013). Generally speaking, the Nigerian Government has shown interest in solar energy development over the past 30 years (Mukhopadhyay and Odukwe, 1985). However, a majority of the studies were focused on rural electrification and most were demonstration projects (Adeoti et al, 2001; Oparaku, 2002). One of the earliest studies that considered large-scale PV utilisation in urban centres focused on Lagos (Fagbenle et al, 2003) and the above mentioned points about the city was part of their rationale.

There are other more important factors for choosing Lagos as a study location and it includes the following:

- Solar radiation intensity
- High urban population and domestic energy users
- Diverse mix of people encompassing the affluent, middleclass and poor
- Good portfolio of dwelling types (especially those suited to roof-top PV)

The most obvious condition for investing in any energy technology is resource availability. The average solar radiation potential of Lagos has been given as between 3.54 and 5.43kWh/m^2 day (Fadare, 2009) which is ideal for PV utilisation. In addition, Lagos is a coastal city which means that it is not excessively hot like the northern states. Cooler climates support PV use. This is why, despite low overall solar insolation in a location like Ireland, improved module efficiency was recorded (Ayompe et al, 20011). There is empirical evidence that extreme heat affects PV performance and accelerates degradation. There have been instances of such occurrences in Libya and Mali (Fathi and Salem, 2007; Diarra and Akuffo, 2002) which largely share similar climates to most northern parts of Nigeria. These locations have regular temperatures in excess of 40^{o}C. This is not to insinuate that PV cannot be used by households in locations with extreme temperatures. It only means that other solar energy systems (e.g. CSP and CPV) are more suited to such areas as they use mirrors to capture the required radiation necessary for normal function. The solar radiation intensity of Lagos is therefore excellent for roof-top PV installations.

Factors related to household population and energy demand were also taken into consideration. The household has been described as a social decision-making unit (Loveday et al, 2008). Since this research investigates barriers to PV adoption with the intention to encourage more household-level PV adoption, the role of this group towards understanding purchase behaviour was deemed vital. In addition, in the valuation of PV generated power, the domestic energy sector will prove useful for this study.

At 47% the population of urban households in Nigeria is close to that of the world average of 53% (World Bank, 2015) which can be taken advantage of in PV promotion and energy efficiency programmes. Lagos State alone accounts for almost 80% of the total urban population at 37% (Lagos State Government, 2014). This means that it is a desired destination for both rural-urban and urban-urban migration. It also implies that energy consumption will be relatively high compared to other parts of the country. There is countless evidence of energy consumption in dwellings representing a bulk of total energy demand. There is also a link between this high energy demand and income (Sardianou and Genoudi, 2013).

Rural residents on the other hand are a majority low-income households and many cannot afford PV even solar home systems (<100Wp) (Wamukonya and Davies 2001; Jacobson, 2007). Most rural residents in Africa tend to be small-scale farmers and rely on their families' resident in cities for remittances. In fact, some have argued that since rural dwellers use mainly biomass for cooking that electricity is not an important option for them (Karakezi and Kithyoma, 2002). Rural dwellers often work for subsistence. As a result the use of PV in rural locations has been primarily driven by donor programmes like the Global Environment Facility (GEF) and World Bank (Gujba et al, 2012). Rural households also lack the knowledge and technical skills required for using such power systems, as studies have shown (Tillmans and Schweizer-Reis, 2011). Their cultural beliefs can also impact PV uptake and use (Sovacool, 2011).

There are other socio-economic benefits of promoting PV and energy efficiency programmes using urban residents against the rural population. Colenbrander et al, (2015) found that promoting PV and other low carbon energy technologies in cities is proactive and will save expenditure on consumer utility bills, governments' subsidies and save costs of investments in energy infrastructure. Moreover metropolitan households have been proven to be the most willing-to-pay for RETs than rural residents (Soon and Ahmad, 2015).

Also, the household sector in urban Nigeria represents the higher income earners and the biggest energy consumers. They are also more likely to have other sources of income (Nigerian Bureau of Statistics, 2012) than their rural counterparts. This is the case particularly in major cities like Lagos and in metropolis everywhere. Although Lagos would be expected to have a greater proportion of educated people and high income earners, choosing this location is not entirely for these reasons. Following a grassroots approach would mean that residents in the 20 Local Government Areas (LGAs) were reached irrespective of their social class. The results which will be presented in the next chapter will show this coverage in greater details. However, because level of PV awareness, familiarity or general knowledge is crucial in the adoption decision (Yoo and Kwak, 2009; Claudy et al, 2010), this was considered in the choice of location.

Lastly, there is a relatively good mix of building types in Lagos that are of potential in PV use. In Ikeja and Badagry LGAs there are mainly regular flats and tenement flats (more in Badagry especially Festac area). Other more affluent neighbourhoods like Ikoyi and Lekki in Lagos Island and newer developments in Epe LGAs have more of the detached houses generally referred to as duplexes in Nigeria. There are also individual housing units and other smaller apartments where people can rent a bedroom flat or room with shared facilities depending on their circumstance.

Dwelling types, size and orientation are extremely important in PV design and installation. This is because of roof-space requirements and related issues of shading or obstruction from nearby buildings which can negatively impact solar gains. Recent studies have shown that microgeneration uptake and WTP for PV can be influenced by dwelling type and size (Claudy et al, 2011; Zografakis et al, 2010; Karakaya and Sriwannawit, 2015). Taking cognizance of these factors would mean that the groups that matter most in PV adoption dissemination are effectively included in the survey.

The demographics of Lagos state is one that very well reflects the situation in the entire country and hence was considered to be representative of the views of the larger population. A representative sample is one whose profile and characteristics is diverse but similar in terms of gender, education and social class to the overall population (De Vaus, 2002). Population used here is a technical term which refers to the set of units that the sample is intended to represent. This depends on the unit of analysis[15] (De Vaus, 2002). All the above enumerated issues were given due consideration in the choice of location. Other more practical reasons for choice of location were limited time, travel considerations and money constraints.

Multi-stage cluster sampling

In the absence of a sampling frame, a multi-stage cluster sampling was used. Multi-stage cluster sampling allows for the division of a city into districts or clusters from which blocks or smaller areas can be obtained. The geographically dispersed nature of Lagos State would require that the city be divided into smaller parts for ease in administration. After the division and sub-divisions study, participants were selected from these more accessible areas. De Vaus (2002) suggests maximising the size of the initial clusters and later selecting fewer individuals or units. Multi-stage sampling is not uncommon in green power uptake studies (Nomura and Akai, 2004; Komatsu et al,

[15] In the case of this study are urban households.

2013). It was used in a recent study in China (Guo et al, 2014) and is effective where there are many LGAs or municipalities that present logistic challenge (Abdullah and Mariel, 2010).

Information collected from the Lagos State House of Assembly (LSHA) library and the Nigerian Meteorological Agency (NIMET) led to the effective use of multi-stage cluster sampling. The LSHA directories were used to organise the LGAs and municipalities. This approach resulted to a breakdown of Lagos State into 5 major districts known as IBILE which is an acronym for Ikeja, Badagry, Ikorodu, Lagos Island and Epe (Lagos State Government, 2013). Through this approach all the 20 Local Government Areas (LGAs) and most of the 37 Local Council Development Areas (LCDAs) were covered in the survey. This meant reaching households across a 30 mile radius.

Similar approaches have been applied in studies to collect data from different areas in a city (Nomura and Akai, 2004; Abdullah and Jeanty, 2011). Using Lagos State administrative zoning structure meant that every household (low, middle and high incomes) were effectively represented. Doing otherwise would have resulted in a biased sample which cannot be used for generalization purposes (De Vaus, 2002). Figure 5.1 illustrates a map of Lagos highlighting areas covered using IBILE zoning.

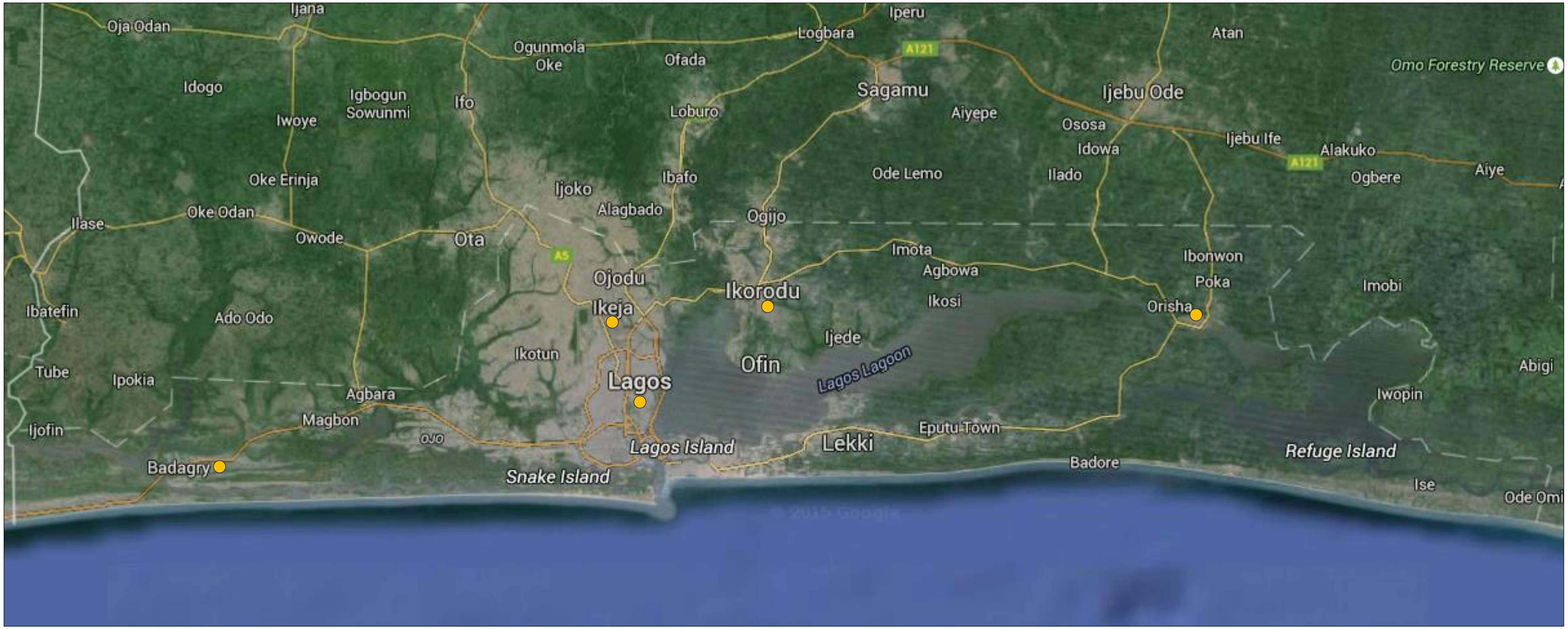

Figure 5.1 Map of Lagos showing location of surveyed households using IBILE administrative zoning structure.

Ikeja is the largest and comprises of 8 LGAs including Ikeja, Oshodi-Isolo, Mushin and Shomolu LCAs.
Badagry comprises of 4 LGAs including Anthony Village which is under Amuwo Odofin LCA and Badagry village.
Ikorodu has 1 LGA known as Ikorodu and is the smallest of the LGAs.
Lagos comprises of 5 LGAs including Lagos Island, Apapa, Lagos Mainland, Eti-Osa and Surulere. It is one of the most elitist areas of the LGAs.
Epe has only 2 LGAs- Epe and Ibeju-Lekki. It is also a generally more affluent area than Ikeja, Badagry and Ikorodu.

Sample size

Since it was intended that the results of the questionnaire surveys be generalizable, a pilot test was carried out. 12 pilot questionnaires were designed and handed out to university colleagues from Nigeria. The remarks and feedback received helped to design a reduced and more self-explanatory questionnaire that was finally administered. Most importantly, this pilot test helped to establish the existence of a largely homogenous sample. As opposed to a heterogeneous sample which often requires very large sample size (Robson, 2002), identifying a homogenous sample meant that a sample size of up to 150 (De Vaus, 2002) would be fitting for the study.

A sample size of around 150 would also ensure higher accuracy and reliability as an increase in sample size from 100 to 156 for instance increases accuracy and reduces the sampling error by 2% (De Vaus, 2002). As a general rule, a sample size should be large enough so that when broken down for the purpose of analysis (e.g. homeowners' versus renters) there will be sufficient numbers in each category (Bryman, 2012). All of the above factors were taken into account during sample size selection. Lastly, the whole selection of sample size was guided by minimal meaningful difference[16] (Tabachnick and Fidell, 2007).

5.2.2 Energy demand audit

Past studies in using alternative energy sources in buildings and promoting residential PV use in particular has shown that understanding the household power needs and usage (Hitchcock, 1993; Sovacool et al, 2011) is a requisite aspect of the desired change. To understand the energy demand of the households, some reasonable assumptions have to be made as to the typical energy demand of the average household, by including the typical household appliances and their power ratings. An energy audit was drawn up to reflect an average urban household's power needs. A similar approach was adopted recently by Chidebell-Emordi in their research which focused in urban Nigeria (2015). The power audit was conducted to ascertain the size of a solar PV system that would be suitable for the average household for the purpose of costing and ensuring adequate supply. For this purpose, solar radiation data from RETScreen software (Appendix H) was used to more accurately determine annual output from a 5kWp PV.

[16] the selected sample size was large enough to allow detection of the least meaningful difference

This audit can be seen in Table 5.1.Through this power audit, the PV array size of 5kWp was noted to be ideal for the average Nigerian household. Often studies indicate system capacity of 3kWp as suitable especially where heating requirements are unconnected to the device. The PV amount quoted in the questionnaire was given by the German PV company EP Scheiba via telephone during the early part of 2013.

While some UK PV companies were contacted for a quote, they all wanted to see the buildings first before giving quotation. Few other Nigerian PV companies such as XYBET Solar and Rubitec Solar Nigeria Limited were contacted but they did not respond, probably because the researcher was not in Nigeria. Travos Solar Company Lagos also later gave a quote which is attached in Appendix E. This quote was supplied in Lagos during the field trip. To make for more robust data points on capital costs, other quotes were collected from PV installers in Lagos and Abuja making for a more reliable estimate. Appendix F and G refers.

Table 5.1 Power audit showing appliance ratings and hours of use

Appliance	Unit	Power/Unit (Watt)	Power (Watt)	Hours in Operation	Daily Energy Requirement (Watt Hour)
Refrigerator	1	500	500	12	6000
Freezer	0	500	0	24	0
Flat Screen TV	1	1000	1000	8	8000
CD/DVD Player	1	30	30	8	240
Air Conditioner (Split)	0	1100	0	12	0
Ceiling Fan	2	80	160	9	1440
Standing Fan	1	80	80	9	720
Computers	2	240	480	8	3840
Light Bulbs	5	60	300	8	2400
Pressing Iron	1	1000	1000	1	1000
Microwave Oven	1	750	750	1	750
Blender	1	300	300	1	300
Washing Machine	1	400	400	3	1200
Water Pump (1/3 HP)	0	1200	0	1	0
			5000		**25890**

From the RETScreen data PV annual output computation:

Available Energy in a Day=7843.39kWh/365days=> 21.49kWh

Percentage Daily Availability = 21.49kWh/25.89kWh * 100 => 83%.

Note: As demonstrated above, a 5kWp PV system will meet at least 80% of the average household demand but this will further depend on the number, ratings and combination of appliances used in the dwelling. The proposed 5kWp PV meets median power demand comfortably and leaves a good margin to accommodate the high starting power of refrigerators. In the case of water pump that runs for a very short time each day (for few households who own them), this can be used when there is mains power supply. However, most listed appliances are non-continuous loads[17]. In this way other smaller devices like mobile phones, tablets and radio can also be easily accommodated. Also, electric cooker was excluded from the list because as would be expected given the power supply challenge most urban households use gas cookers.

5.2.3 Questionnaire design

A questionnaire research design provides the framework upon which the process of collection and analysis of data for a study is carried out (Bryman, 2012). Applying a largely deductive (top down) logic, the questionnaire was designed. Existing literatures and grounded theory largely guided the selection of many of the questions asked. However, there were instances where the contextual needs of the study participants were inquired of. This is usual practice.

Questionnaires have many advantages, hence its widespread usage, but it can have limitations on the amount and detail of information that can be collected. The limitations arise mainly from the semi-structured design of the questions. For instance, for investigating PV purchase decision and energy use behaviour, close-ended or categorical questions are appropriate. But for seeking answers to questions bordering on underlying reasons for PV adoption this would mean that certain important information would be impossible to collect due to the fixed or semi-fixed style of questionnaire surveys.

A larger proportion of the survey questions were close-ended which placed a limit on the amount of responses that could be given by the respondents. However, it gave the respondents the opportunity to give views outside those listed using the ‘other, please state’ option. Obviously, limited information can be provided in such ‘other, please state’ fields. Despite this, questionnaires are best for measuring closed-ended questions (Bryman, 2012). This shortcoming was later remedied by the use of open-format interviews in the second part of this research.

The semi-structured questionnaire was designed to collect key information on the barriers to PV deployment, household stated support preferences, alongside other

[17] They need not be permanently ON and drawing electric power.

important socio-demographics. In the questionnaire some questions may appear repetitive but they were included to serve different purposes. An example is questions 2 (respondents' age) and 4 (age and number of households). The benefit of this structure was that respondents who declined to provide their age in 2 ended up supplying it in 4. Through this medium the age-bands of all the head of households were collated.

Assumptions

As part of the questionnaire design, household value of PV as a power supply source was investigated using the WTP concept. This research assumed the presence of government incentives in the form of grants and FITs. The assumptions were based on the recent commitment revealed by the Nigerian government towards promoting renewable energy, particularly solar using such schemes. It was also based on reports that uptake of PV has been on the rise in Nigeria especially by businesses (refer to previous chapters). Doing this would to some extent help to predict the adoption path when support incentives become available. Also it would prove useful to policymakers for creating and implementing an effective green power policy. The basic principle for measuring the benefits from any proposed policy is the WTP concept (Yoo and Kwak, 2009).

WTP

The collection of data for consumer choice studies can be done with either Stated Preference (SP) or Revealed Preference (RP) methods (Ida et al, 2014). SP against RP was opted for in the questionnaire design. The former is designed to be used when data is extracted from surveys or interviews, while the latter finds application when an observation of the household's choice decisions are made from a set of alternatives in real markets (Banfi et al, 2008; Louviere et al, 2010). SP is advantageous where there is lack of research and market information**.** Since PV is a 'new' technology, it makes sense to use SP due to lack of revealed preference data in studies in Africa (Abdullah and Jeanty, 2011). SP has been widely used for investigating consumer responses to renewables (Scarpa and Willis, 2010; Claudy et al, 2011; Menegaki, 2012; Soon and Ahmad, 2015).

Elicitation methods

Contingent Valuation Method (CVM) was used to evaluate the value to households of PV. Conjoint Analysis (CA) is frequently used in related studies (Borchers et al, 2007;

Ida et al, (2014). Some use discrete choice experiment to refer to CA but there are criticisms that both should not be treated as the same concept. See Louviere et al, (2010) for more details as to the differences. CA was not chosen because it is generally used where the attributes of a product is to be assessed as a means of measuring acceptance. This was not the prime aim of the questionnaire. While some questions explored certain PV attributes, the aim was to identify the barriers and value to households of PV.

There are two principal methods of eliciting responses using CVM. They are open-ended questions and closed-ended questions or dichotomous choice (DC). DC can be single-bounded (SBDC), double-bounded (DBDC) or multi-bounded (MBDC). Open-ended questions can create additional pressure on respondents leading sometimes to a high percentage of non-response (Nomura and Akai, 2004). DC has been applied in researches measuring interests in renewable electricity (Nomura and Akai, 2004; Yoo and Kwak, 2009; Baskaran et al, 2013).

A DC decision typically involves a yes/no format questionnaire design (Komatsu et al, 2011) (for SBDC) which may be followed by a categorised question order in the case of DBDC (Yoo and Kwak, 2009). In the analysis, some researchers use parametric estimates while others use non-parametric estimates (Guo et al, 2014). Some others combine both (Abdullah and Jeanty, 2011). While it is apparent that an extra question in the case of DBDC and MBDC can yield more refined bounds, evidence suggests the efficiency improvements is minimal (Yoo and Kwak, 2009). SBDC has been found to be highly reliable in opinion studies (Wiser, 2007).

Under conventional CVM studies, a bidding process is followed. The respondents are offered prices for RES-E or PV. In the initial round, respondents will have to choose 'yes' or 'no' from listed prices for PV or percentage of carbon reduction etcetera (Ida et al, 2014). Respondents who select the 'yes' option to a price are led to a higher bid while those who select 'no' are omitted from the next question. Another problem that can arise from such extra questions is response effects or bias resulting in internal inconsistency (Yoo and Kwak, 2009). The bidding process normally follows a banding. For instance, respondents could be made to choose from a list such as:

Cost of PV = a) \$10,000, b) \$15,000, c) \$20,000, d) \$25,000 and
Percentage reduction in GHGs = a) 15%, b) 20%, c) 25% d) 30% etc.

The above traditional bidding process often applied in CVM studies was considered unnecessary in this study. First, due to the dismal history of national power supply, it was decided that the use of price bids would yield insignificant results hence be ineffective. It is when people are satisfied with an existing power supply that they can be more responsive to a newer more expensive supply source. Secondly, studies that use this form of elicitation rely mostly on electronic questionnaires, telephone and face-to-face interviews (Yoo and Kwak, 2009; Scarpa and Willis, 2010; Oliver et al, 2011). Nomura and Akai (2004) did not clearly state the mode of mail survey delivery but it appears to be postal using printed questionnaires[18] (p.455).

In bidding exercises, rates are increased or decreased accordingly based on response. Therefore, the question ordering becomes important even in hypothetical studies. To deal with this, Nomura and Akai (2004) reported that they placed the questions on separate sheets in the questionnaire in the belief that the second question would not be seen by the respondents before answering the preceding question.

In an online survey, this problem could be easily prevented as the questionnaires can be designed in such a way that a page is completed before the next pages can be accessed. Thus, the view by Nomura and Akai (2004) is invalid in a printed questionnaire as respondents do not necessarily complete forms sequentially (personally observed). They may scan through the questions first. When this happens, it can bias bidding results if the design is like that of Nomura and Akai (2004).

Because the questionnaires in this study were to be hand delivered, the bidding process had to be different. A more straightforward CVM similar to that of Hite et al (2008) and Nomura and Akai (2004) was adopted following a SBDC method. The respondents were given a minimum quote of £16,000 (i.e. ₦4 million at exchange rate N250 per £1) for an ideal PV capacity of 5kW to provide at least 50% of the energy needs of their home. A kind of negotiation involving listed incentive discounts in the form of percentages was used rather than cash bidding. The levels were 25%, 30%, 40% 50% and 60% with the ‘other please specify’ option. The option selected by the respondent was then deducted from the total cost of PV quoted. So if a respondent selected 50%, it meant they were prepared to pay ₦2,000,000 (£8,000) and so on and so forth.

Although respondents were initially asked if they would pay a higher amount for improved grid electricity, later they were presented with the opportunity to privately pay

[18] Internet access was not widespread then.

for PV and possibly grid-tie. For the purpose of gauging acceptance, the questionnaire had to assume the presence of support incentives such that the household had to make part payment. Kim et al (2012) employed a comparable approach that assumed the presence of RPS in South Korea.

5.2.4 Questionnaire completion order

The head or decision maker of each household surveyed was required to complete the questionnaire. In all, the questionnaire format took the form of opening questions, intermediate questions and closing questions. Warm up questions were asked at the questionnaire opening to engage respondents. Other data collected were related to household PV awareness, barriers to uptake, environmental consciousness and WTP. The questionnaire had seven aspects but with four goals which were compatible with the use of this research approach:

- Identification of the socio-demographic profile of the urban households (questions 1-13). This included household size, building type, housing tenure, income and education.
- Revealing household knowledge of the impacts of uncontrolled energy use (questions 14-18). This included questions on environmental awareness, curtailment behaviour and energy bill checks.
- Understanding general energy demand (questions 19-28). This included hours of electricity supply received, amount spent on back-up energy, willingness-to-pay a higher amount and general satisfaction with grid electricity.
- Anticipated response to PV and the likely effect of incentives (questions 29-43). This comprised of questions on PV awareness, barriers to uptake and willingness to pay and grid-tie.

The final questions (44 and 45) specifically enquired of PV users. The aim was to identify early users who would be interested in participating in the interviews. Appendix A contains a copy of the questionnaire used in this study.

5.2.5 Questionnaire administration

While the questionnaires benefited from a pilot test using 12 individuals from the target group, the absence of a sampling frame meant that the distribution had to be planned using alternative means of delivery. Emails sent to the government departments in Lagos were not responded to and visits yielded little result. Information received from the Lagos State House of Assembly library was very helpful in identifying the respective districts, municipalities and households.

This was done to ensure a more representative and fairer sample while maximising the outcome. A key issue that often arises in the use of cluster administration is deciding how many clusters (in the case of this study, households) to sample at each phase (De Vaus, 2002). The solution was to distribute the questionnaires according to the size of each district. Bigger clusters received more questionnaires and vice versa. For example, because the 5 zonal districts had varied geography and population sizes, more surveys were administered in larger areas such as Ikeja than Epe which is a much smaller district.

Using this information, a multi-mode method of questionnaire administration was devised. This involved the use of hand delivery and postal distribution methods. The questionnaires were distributed between November and December 2013 and were accompanied by a letter from Heriot-Watt University detailing the purpose of the research **(**see Appendix A). Hand delivery has the advantage of ease in administration. Also, the low internet access would mean that online questionnaires would be difficult to administer. However, an online survey was originally created using Lime software bearing in mind that some respondents might request it.

The researcher employed the services of 10 field assistants to help distribute and collect the completed questionnaires. This comprised of 4 family members and 6 friends who have lived in Lagos all their life. In appreciation for their help, most received gifts with monetary value of £25. Some of the field assistants were given travel money or petrol for using their vehicles. In total, 245 questionnaires were administered. Most were hand delivered but 40 were sent via email. A total of 200 usable questionnaires were returned representing a response rate of 82%. Of this total, only 3 were electronic copies.

The response rate can be attributed to the sentiments attached to the national power supply problem and to the public’s approval of general developments in Lagos State. Recent infrastructural transformations in Lagos state under the leadership of Governor Fashola was one applauded by many. As a state government with a very high opinion rating, the participation rate and the seriousness given to responses would have been positively influenced by the Governor’s image and the belief that the survey results would be eventually acted upon.

5.2.6 Handling questionnaire survey bias

Research cannot be conducted without researcher values impacting it. To suppress personal beliefs and worldviews, certain controls were put in place helping to reduce bias. Bias controls are necessary to minimise error and prevent over prediction. In stated preference studies, a common problem is hypothetical bias which arises due to changing circumstances and the fact that stated preference is not the same as actual preference. There is also the likelihood of overbidding (Wiser, 2007). This means that in real-life situations, consumers may act contrary to what they state in questionnaire surveys. To prevent such happening the respondents were presented with the part payment option. This does not only reduce the total costs but also shows that it is a collective effort which most households are likely to appreciate.

Ordering or sequence bias

To deal with bias associated with the question order, the questionnaire was split into sub-sections with questions separated in a way that the links could not be easily spotted. For example, the question asked regarding household WTP more for grid electricity was placed on page 4 of the questionnaire while that of PV costs and incentives was supplied in pages 6 and 7 under a completely different sub-title. The PBT question was placed in between the PV price quote and the question relating to amount of grant/incentives favoured which was also placed on a different page. This was after providing the respondents with a brief introduction of some benefits of PV. These efforts help to reduce bias and make results more reliable (Kim et al, 2012).

Interviewer or field assistant bias

Guo et al (2014) rightly stated that in a face-to-face mode of questionnaire delivery, respondents may select ‘yes’ so as to satisfy the researcher. This is unsurprising. The authors further said that after initially explaining purpose to their respondents, they controlled bias by choosing not to provide any further guidance to the respondents for the 25-30 minute interval it took to complete the survey forms. Even experts may sometimes require further explanation when the researcher is present. Their mode of bias control makes the survey exercise cumbersome for willing respondents. Applying such a control can be difficult and hence doubtful in a face-to-face survey. It would be easier and more effective to implement controls related to field assistants in a hand delivered or postal survey, as all that the researcher has to do in the majority of cases is return to pick up the completed questionnaires.

Title bias

Finally, a bias that has not been mentioned in literatures read is that related to questionnaire title. Respondents can pick up clues from titles that may influence responses, thereby affecting results. For this reason, the questionnaire title was carefully selected. It simply read: "Energy supply for urban household use in Nigeria." This is not to suggest that researchers deceive respondents by applying unrelated titles. Instead, it means that researchers should withhold certain key information that could bias results. Finally, in order to reduce problems associated with non-response e.g. missing data, some type of questions were deliberately omitted from the questionnaire. For example, questions asking for exact income details were excluded. People can be sensitive and uncomfortable with questions related to their earnings. To make for maximum response, a banding was used instead.

5.2.7 Questionnaire analysis

All of the survey questions were pre-coded to enable quicker data transfer and analysis. Upon the receipt of completed questionnaires, additional coding was applied. This arose mainly from some responses to questions which created a need for further coding allocation. Multiple data checks were carried out and cleaning performed where data entry errors were identified. This is often advised when quantitative data analysis softwares are deployed in a study (Pallant, 2011).

The SPSS software (IBM Statistics Version 22, 2012) was used in the questionnaire analysis. A 5% significance level was set for all tests carried out. In order to accurately measure the size of the anticipated effect e.g. (expected mean difference) and the variability expected in the assessment of the effects (Robson, 2002; Tabachnick and Fidell, 2007), power analysis and sample size tests were carried out using the free PASS software available on the NCSS website.

In general, three key techniques were employed in the questionnaire analysis. The first part involved the use of descriptive statistics such as frequency tables, cross-tabulations and contingency tables to examine the data in order to evaluate opportunities for further analysis. Noted patterns were subjected to tests of significant relationships and differences leading to the identification of further interesting trends. The methods used here included bar charts and box-plots. While the frequency tables explored demographic characteristics such as age group, household types and home ownership, the bar charts and box-plots were useful for identifying the relationships between the different categories of income and education levels across gender and age groups.

The second part of the questionnaire analysis involved the use of inferential statistics. After carrying out normal distribution tests using Kolmogorov-Smirnov and Shapiro-Wilk normality tests, Spearman's Correlation analysis was used to check existing relationships, strength and direction of the relationships. The tests were reported detailing the statistics i.e. correlation coefficient (r) and probability (p). The Spearman's correlation analysed the association between socio-demographics, barriers to PV adoption and likely motives for PV uptake.

Correlation finds application in consumer response and WTP studies. As previously noted in Chapter 3, Oliver et al, (2011) used Spearman's correlation in their analysis. In this study, the asymmetrical distribution of most variables in the dataset precipitated the use of Spearman's correlation rather than the more prevalent Pearson's correlation. Spearman's correlation is a non-parametric statistic which has the advantage of not placing certain limits where datasets are nonlinear, curvilinear and not completely normally distributed (Tabachnick and Fidell, 2007). Grothmann and Reusswig, (2006) examined consumer response to risk of flooding in Cologne, Germany using Spearman's correlation and logistic regression with successful outcome.

The final part of the questionnaire analysis made use of a binary platform to predict the path PV adoption will take in Nigeria given certain conditions. Using Binary Logit Models or Logistic Regression as it is generally known, the collective predictive power of significant correlations were investigated. Logistic regression is a form of generalized linear models that uses algorithms of Maximum Likelihood Estimates (MLE) to predict the probability or logs odds-ratio of an outcome (Tabachnick and Fidell, 2007). The goal of the MLE procedure is to find the best combination of predictors to maximise the likelihood of obtaining observed outcome frequencies.

In their study, Claudy et al, (2010) made use of logistic regression. More recently, in a study on consumer attitudes to renewable energy in China, Hast et al (2015) applied logistic regression. Others have used similar methods by employing binary probit (Sardianou and Genoudi, 2013; Komatsu et al, 2013) bivariate probit (Claudy et al, 2011) and multivariate probit (Baskaran et al, 2013). Probit finds application where datasets are symmetrical. The major difference between binary probit and binary logit is the transformation[19] applied to the proportions that form the dependent variable (Tabachnick and Fidell, 2001).

Lastly, in logistic regression, the odds ratio is the increase or decrease in odds of being in one outcome when the value of the predictor increases by one unit (Ryan, 1997). The techniques are further discussed in Chapter 6 but the steps taken included plotting relevant statistics such as Chi-Square (χ^2), degrees of freedom (*df*), Cox and Snell R Square or Nagelkerke R Square and finally the Hosmer and Lemeshow Tests. For example, by combining few of the households' (respondents) sociodemographic profile such as income and education and other significant dependent/predictor variables into a model, it was possible to forecast what could happen once PV is supported through policy. The next section presents the qualitative methods and strategies used in this research.

5.3 Research strategy: Qualitative research methods

This part of the study relied upon interviews as the primary medium of data collection. Some of the interview questions were drawn from literatures (that is, grounded in theory) while others were created based on the societal context of the respondents.

5.3.1 Grounded theory

Although sometimes used to generally refer to studies that move from theory to observation, grounded theory is a qualitative strategy. It is a deductive approach that derives from a generic, abstract theory of a process, action or interaction grounded in the views of the participants in a study (Creswell, 2007). In addition, grounded theory implies not only that the researcher has grounded the research in theory, but has also used data management tools of coding to organise the concepts and themes until a point of saturation[20] is reached.

Grounded theory is useful where there is lack of theory and concepts and when data collection, analysis and theory development and testing are intermingled (Robson, 2002). Dearth of empirical research and literatures on urban PV adoption (both residential and commercial) in Africa as a whole supports grounded theory (Soon and Ahmad, 2015). Although research exists on the topic, in OECD countries most accounts

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[19] While logistic regression uses logit transform probit uses probit transform.

[20] The point where an increase in the number of cases or where further codes applied to the transcript data was no longer value-adding (Bryman, 2012).

are insufficient and do not fully address the slow PV adoption problem particularly as it pertains to households. Where they do, the findings are mostly location-specific.

In consequence, there is a high likelihood that some relevant issues as it affects developing countries are not covered in these existing studies on household-level PV adoption in advanced economies. Where such useful piece of research is missing, there is a chance that some lessons that could have been learnt are lost and the potential benefits to carbon mitigation drive are unexploited.

To investigate the drivers of PV uptake by urban households, interviews were considered the best fit for purpose. This was especially important given that globally only a small number currently utilise PV (Balcombe et al, 2013). An inherent feature of grounded theory is that of continuous review and comparison of the dataset. Evidence suggests that coding in grounded theory is more iterative than in questionnaire surveys as a result of the frequency of revision it entails (Bryman, 2012). Using grounded theory meant keeping a close link between data and relevant concepts such that the relationships and *underlying* meanings are kept intact (Creswell, 2007).

Another reason for taking a grounded approach was due to the distinction in coding motives between questionnaire surveys (quantitative research) and interviews (qualitative research). For the most part, while coding in questionnaires is designed primarily with the researcher's interests in mind, the coding efforts in interviews are mainly directed towards the participants' concerns (Bryman, 2012). This is because in the former, codes are to a large extent pre-assigned through the question structure used in the questionnaires. The 'other, please state' option often does not collect much information. However, in the latter, the use of coding occurs after data collection and in the course of transcription and analysis.

The researcher's interpretation and meanings given to *real life situations* are drawn from the emergent codes, themes and concepts in the transcript material. Although coding can be assigned after data collection in questionnaires, such post-coding is carried out to enable the researcher to manage the survey data (Pallant, 2011). Another approach that was considered applicable to this research is the case study approach. Figure 5.2 is an illustration of the qualitative approaches adopted.

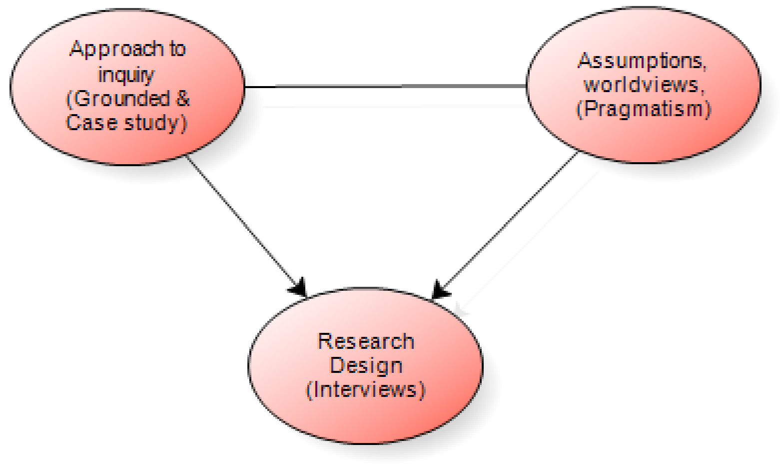

Figure 5.2 Model of qualitative research adopted

Adapted from (Creswell, 2007)

5.3.2 Case study approach

As pointed out earlier, researchers advocate the use of the philosophical and methodological approach that works best for a particular research problem (Denscombe, 2002; De Vaus, 2002). Such reasoning underpins mixed methods research (Robson, 2002). Case study research is a strategy of enquiry that studies an issue by the examination of one or more cases within a setting or context (Creswell, 2007). It is suitable for mixed methods studies (Yin, 2003) and is generally distinguished by the size and the intention of the case analysis.

In case study research, the case can be a situation, individual, group or whatever is of interest (Robson, 2002). Thus, case studies can be carried out on individuals, a programme, a service or an innovation. When carried out on individuals (multiple cases), it entails giving *detailed accounts* of the small number of individuals often involved. This it does by providing the relevant *contextual* factors impacting on the individuals' attitudes and perceptions before any decision or outcome (Robson, 2002). Thus, the context or setting of the study is of significance and plays an important role towards the outcomes.

The *setting* is vital in a case study because the case always takes place in a specific social and physical setting with individuals that share similar characteristics (Robson, 2002). The interview initially focused on PV adopting households in Lagos State, Nigeria. But the shortage of PV users and challenges securing interview appointments meant that PV users in Abuja, Delta State and nearby Edo State were also interviewed. This turned out to be beneficial as the opinions of adopters from varied backgrounds were received making for diversity of views and a better reflection of the population under study.

Creswell (2007), suggests that multiple case studies is suitable for a single investigation but with multiple cases to illustrate issues with the aim to portray *different perspectives* on the problem under investigation. The goal of this aspect of the study was to first and foremost answer the second research question posed: the motivations for PV adoption. The questionnaire survey primarily addressed the hindrances to PV uptake and WTP which resulted in the identification of few residential PV users. In order words, this interview is an offshoot of the questionnaire surveys and serves to also complement it.

Case studies are the design of choice where the theory is likely to propose either the same result previously established, or where different results would probably be obtained (Robson, 2002). The outcomes of case studies can be multi-layered and difficult to capture solely using simple theories (Robson, 2002) hence allowing themes and theories to evolve from the data can be expedient. The context, setting, level of details, differing perspectives and underlying meanings can only be efficiently collected via interviews.

Since the purpose of using these approaches was not only to explore (gain insight into what is happening in the residential PV sector in Nigeria) but also confirmatory (to provide an explanation by comparing with established findings), it was considered pertinent to combine research designs. The hybrid approaches of grounded theory and case study are flexible designs with much relevance to real world situations (Robson, 2002).

5.4 Location, sampling and justification

The interviews were conducted with participants in Nigeria. Like the questionnaire sample, a larger proportion of the interview participants were drawn from Lagos State. Lagos is the largest city by population and has a diverse mix of the Nigerian people from all 37 states of the federation. Other interview participants were taken from Abuja, Delta and nearby Edo State. While participants were taken from 4 states in Nigeria, the unit of analysis was the PV adopting households and not the cities.

The aim of the interviews was to examine the motivations for PV adoption in Nigeria. Such requisite information could only come from the energy end-users who are the domestic PV adopters. Because the majority of urban households have been deprived of regular power, the overarching purpose of the study was to help assess ways by which power supply and consumption in Nigeria can be improved sustainably.

Purposive sampling

Research indicates that sample size decisions in mixed or flexible designs should be based on the scope of the data, nature of the topic under investigation, data quality and research methods (Robson, 2002). Purposive sampling method guided the selection of interview participants. In this type of sampling, the researcher's judgment is relied upon based on study interest and rationale. Purposive sampling is a generally acceptable technique in mixed methods (Robson, 2002). Three of the PV adopters were identified from the questionnaire survey. Others were selected via referral[21]. In most cases, adopters knew someone else using solar PV and may have had their panels installed by the same technician.

Though PV is a new innovation, globally it is the most popular renewable power technology (Islam and Meade, 2013). This appeal and acceptance of PV has meant that it is a topic that many people are somewhat familiar with due to its high visibility. Aside the obvious sentiments tied to electricity shortages in Nigeria, PV discourse creates interest from members of the public. As regards data quality as a sampling selection criterion, the 14 adopters interviewed provided deep and rich data. Richer and experiential data requires fewer participants (Robson, 2002). Lastly, the in-depth semi-structured interviews used as research methods generated large volumes of informative data by the eleventh interview when signs of saturation were already apparent.

Aside reaching theoretical saturation, finding PV adopters presented a problem. This further led to limiting the interviews to 14 PV adopters. In addition, the difficulty faced in the course of finding PV users led to the interview conduction lasting for approximately six months (November 2013-April 2014). The difficulty of locating PV users arose from the fact that despite PV's popularity, it is still a novel technology. This means that Nigeria currently has a small number of domestic PV users. This limitation also led to the inclusion of PV adopters outside Lagos.

[21] This is the case where an adopter interviewed refers the researcher to other adopters.

5.4.1 Interview design

Open-ended semi-structured interviews were used in this study. Semi-structured question-type allows for greater flexibility in the questioning and in the response taking as the responses can be given outside the original order of the interview guide. Open-ended questions have the advantage of encouraging the interviewees to reveal as much information as possible. They generate a more elaborate response to questions than closed-questions widely used in questionnaire surveys.

Interviews can be very useful when the investigation as to the rationale for a decision is sought. In this study, the purpose of using the interviews was to provide answers to what the motives for PV adoption are and to gauge what could possibly lead to increased uptake from the perspectives of the early PV innovators. Research has shown that interviews are good strategies in consumer attitudes to green power (Scarpa and Willis, 2010; Menegaki, 2012), adoption theories (Creswell, 2009; Sovacool et al, 2011) and when explanations for purchase decisions are requested (Ahlborg and Hammar, 2014; Yamamoto, 2015).

Interviews have the added advantage of being cost-effective, especially telephone interviews which eliminates the need for travel in geographically dispersed locations like Lagos. Telephone interview is also useful when the interview does not take too long. A key disadvantage of telephone interview is that the body language of the interviewee cannot be observed and technical glitches may arise. This leaves the researcher with using the adopters' voice pitch or tone as cues to monitor the unseen.

Interview questions

The interview questions were predominantly aimed at uncovering the key motivations behind PV uptake. The questions were designed to gain an understanding of the motives for PV adoption from the few households who had invested in them. Finding out the true motivation behind adopters decisions would be helpful towards understanding the reasons behind non-adoption by other households. The interview was also designed to elicit views on user experience and how PV use had impacted household energy consumption and behaviour. It was further designed to capture early PV adopters' thoughts on support incentives.

Questions were designed to discern the benefits of a feedback mechanism such as PV monitor by examining the pre and post-purchase behaviour and attitudes of the adopting households. Understanding the effects of PV uptake on the adopters overall energy demand and the behavioural modifications would be the foundation for any energy efficiency bid. Thus, the interview survey was designed primarily to uncover the factors driving private sector PV uptake in a society where most households are still utilising petrol and diesel-powered generators as back-up power. It was also the intention of the study to examine the extent to which factors outside finance and economics influenced the PV purchase decision. The reason being that recent research has shown that while costs are a very important factor, on its own, financial considerations are an inadequate measure of PV investment decision (see Chapter 3).

The initial interview questions were pilot-tested with the help of two colleagues from Nigeria. The pilot tests were hugely helpful as it led to some amendments to initial questions, with a further reframing and reordering of some of the questions. The interview questions format took the order of the opening questions, the intermediate questions and the final questions, as recommended by Charmaz, (2006). The opening questions enquired of the adopting households' PV capacity and duration of use. While this line of questioning was created to make the PV adopters feel comfortable, it was very important to establish duration of PV use, as a very recent installation would not have been of great benefit to the study.

The intermediate questions largely examined the role of feedback mechanisms such as PV monitor. The final questions covered maintenance issues, challenges and likelihood of recommending PV for other households. This system of interview questioning is generally endorsed in social and behavioural qualitative studies (Charmaz, 2006; Creswell, 2007). In the framing of the words used in the interview guide, special attention was given to the language structure recognising that the design and format can greatly affect the responses and overall study (Kvale, 1996). Care was also taken in the choice of words used. Question types were varied to keep the PV generating households interested.

The term solar panel was mostly used to refer to PV and complex terms and language was generally avoided. Only terms the adopters would be familiar with were employed in the interviews. It is important to state here also that the unit or metric the households used to refer to their PV size was KVA. This is a common term used in Nigeria to describe power systems. It may have been the result of long term diesel and petrol generator use often expressed in KVA. However, for the purpose of this research, this was converted to kWp using an online power conversion tool.

5.4.2 Face-to-face and telephone interviews

The qualitative aspect of this study relied upon interviews (face-to-face and telephone). Four of the PV adopters were interviewed face-to-face in Lagos, Nigeria. Ten telephone interviews were conducted upon return to the UK. The calls were made using the landline due to the duration of the calls and a quieter office recording space. Besides, the use of a mobile for 45-60 minutes was deemed too costly for the researcher. A quiet space and adequate preparation is crucial to a successful audio-taping of an interview.

Lastly, though the questionnaire survey revealed that thirteen of the respondents owned a solar PV system, three users participated in the interviews. Aside socio-demographic profile, the interview questions generally covered relevant aspects such as system size, drivers, role of PV monitor feedback, energy use efficiency, payback time and challenges and suggestions for increased uptake. Although an interview schedule was used, the questions did not take any particular order. The reason was that some of the adopters presented their answers in ‘their own way’. They were free to do so as ‘rambling’ is encouraged in interviews because it gives the opportunity for surprise statements (Bryman, 2012). In fact, it is the basis of qualitative research to allow the respondents to say as much as possible, because, in doing so, the unexpected comes through. This unexpected can become the most significant part of an inquiry as this study proved. As a result, for some PV adopters, the interview guide was followed through as designed but for some others it was not adhered to.

This did not constitute any problems because the researcher only had to return to skipped questions later on. There were also occasions when the adopters will disclose some answers to questions yet to be asked which meant that they were later omitted. This flexible approach to interviewing made possible the exploration of alternative avenues of enquiry. However, the researcher maintained control and ensured the right balance using tact throughout the interview process. Furthermore, where questions were misunderstood, they were repeated. This did not happen often. Appendix B contains a sample interview transcript.

5.4.3 Interview data management and analysis

All the interviews were recorded using the Sony MP3 sound recorder. The recorded interviews were first manually copied and later transcribed onto A4 sheets. The transcription resulted in 42 A4 pages of textual material. This gave an average of 3 A4 pages of text per adopter interview. However, the need for added transparency was noted early on leading to the consideration of alternative methods of qualitative data transcription and analysis.

For increased clarity and to keep an audit trail for the interview data, a Computer Assisted Qualitative Data Analysis Software (CAQDAS) known as NVivo was used. The benefits of NVivo in data analysis are widely appreciated (O'Neill, 2013). NVivo allows for a robust data capture and in combination with manual coding leads to a richer and more thorough data analysis output. The NVivo analysis software used enabled efficient data management which ensured that the relevant concepts and themes e.g. (socio-cultural and environmental factors) often associated with influencing PV uptake were identified. For instance, even after setting aside foreknowledge of the determinants of PV uptake based on existing literatures in relation to the adoption motives and barriers, the coding process repeatedly revealed socio-economic drivers as important. Since the basic intent of a grounded theory study moving beyond mere description, is to discover a theory (Robson, 2002; Creswell, 2007). Its use in this study was seen to be of paramount importance.

Setting aside a foreknowledge of existing theories used to explain the determinants of PV adoption does not imply that the interview coding analysis completely ignored established research. Besides, it is impossible to do so. Rather, it signifies that the researcher was open-minded and sought to see new patterns, concepts and theories emerge from the interviews. Robson (2002) pointed out that holding tightly to established conceptual frameworks and theoretical views has the downside of 'blinding' the researcher to important aspects of the case(s) which can result in misinterpretation of evidence. The data analysis steps taken are represented in Figure 5.3 below.

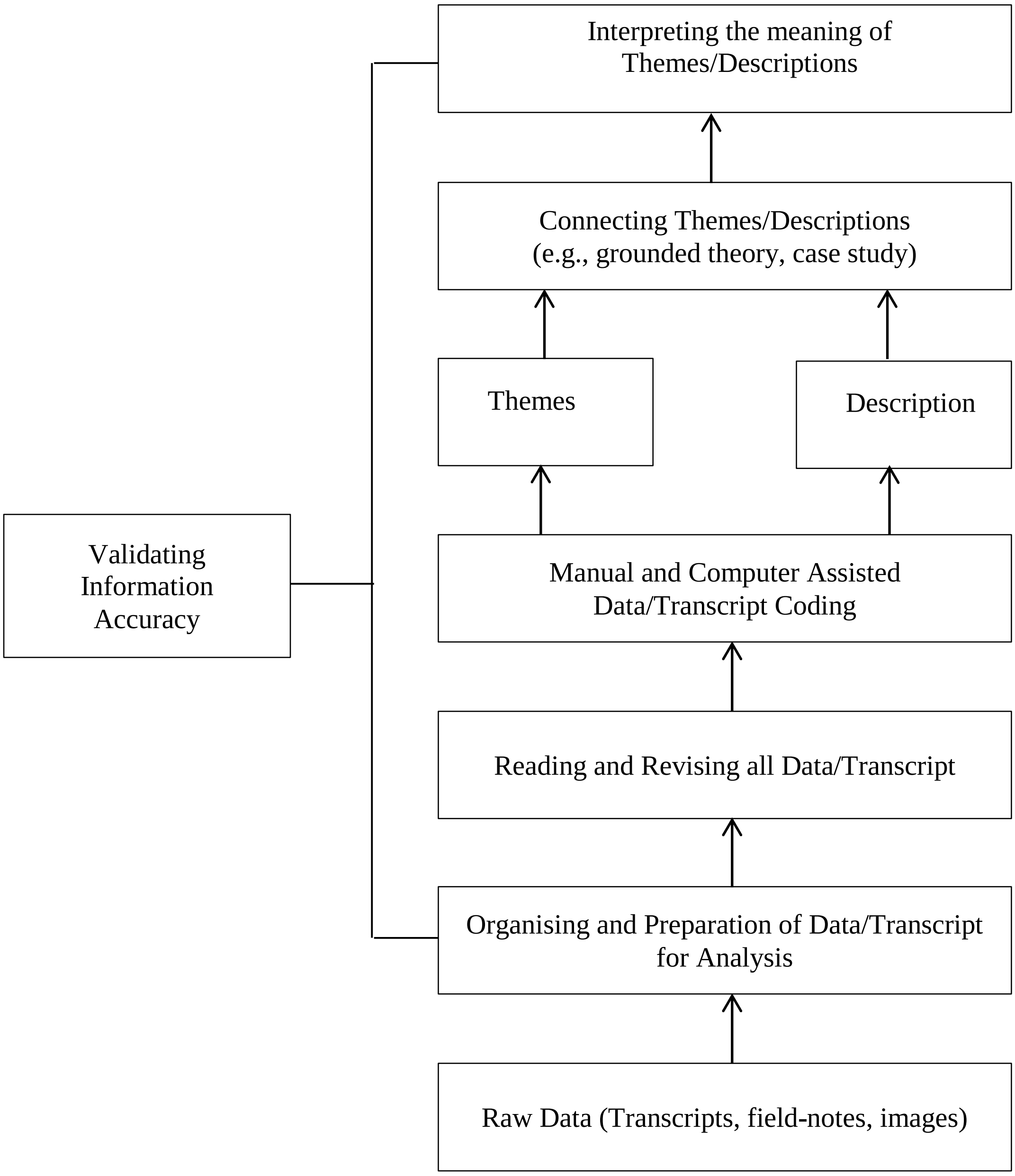

Figure 5.3 Data analysis steps adopted in interview

Adapted from Creswell, (2009)

5.5 NVivo analysis

While the auto-coding feature of NVivo can make for faster thematic analysis, the feature was not deployed mainly because of the semi-structure format of the interview questions. This structure meant that there was no strict order in the answers to questions and hence making it infeasible to apply auto-coding to the data. A process also referred to as coding NVivo. As a result, right from the data collection (interview conduction and recordings) down to the data analytics, a meticulous approach was taken. For example, during the transcript stage, data was transcribed on a 'document per question' basis rather than a 'document per respondent' basis.

Organising the data transcription on a 'document per question' basis implies that all the responses to each question were analysed across all interviewees at the same time. On the other hand 'document per respondent' transcription format is an approach that involves analysing data on a case-by-case basis (Creswell, 2009). Although this analysis approach was time consuming, it had the advantage of unearthing minute details that would otherwise be overlooked. It was actually decided upon given that there were 14 interviews. In cases over 50, it would be impractical to follow this method.

Given the nature of this study, it was further considered vital not only to confirm existing theories but also to identify new concepts that could result in an improved understanding of renewable self-generation. In the interview analysis stage, grounded theory aided in the explanation of the prime determinants of PV adoption in Nigeria. Questions asked during the data analysis included:

- What *led* to the adopters' decision?
- What were the PV households' *experiences*?
- What *strategies* did they use to cope with PV limitations?
- What *consequences* resulted from these strategies?
- What *did they learn* from their experience of utilising PV in terms of its higher interactional involvement compared to grid power?

Through the use of charts and visual models, the factors that influence PV adoption were analysed applying different degrees of abstraction as suggested by Robson (2002) and Creswell (2007). Additionally, the application of a case study approach during data analysis allowed the vivid description of the interview setting by presenting it in the context showing the many processes involved. The layering of themes led to the merging of central concepts such as the technical drivers and the socio-economic motives for PV uptake. Key questions explored include:

- What *theoretical constructs* aided the comprehension of responses and emergent themes?
- What was *unique* in the responses?
- What *themes* finally emerged?

The grounded theory and case study driven questions above gave the researcher an opportunity to interact with the data in a way that would have been impossible through questionnaire. Table 5.2 shows the steps taken during the NVivo data analysis.

Table 5.2 NVivo analysis phases followed

Adapted from O'Neil (2013)

NVivo analysis phases	Steps taken at each phase
1. Descriptive Phase	Interview transcript review
	Inputting sources
	Assigning attributes
	Creating values
	Creating classifications
2. Topical Phase	Identifying key themes
	Creating initial nodes
	Creating memos
	Preliminary coding
3. Analytical Phase	Merging nodes into hierarchies
	Text search/word frequency queries
	Final coding/matrix coding queries
	Creating models and relationships
4. Conclusions	Cross verification
	Validation and theory development

Phase 1: Descriptive

After reviewing the interview transcripts the interview recording files were first uploaded onto the NVivo software. The adopters' demographic details created using Microsoft Excel were then transferred onto NVivo. This was followed by transferring photos taken and notes made during the field trip onto the programme. Assigning attributes, creating values and classifications came afterwards. The source and node classification tool was instrumental to the setup of the adopters' demographic data in a way that allowed for meaningful use.

The node classification tool enabled the linking of the 14 adopters' socio-demographic profile (characteristics and other values) with identified themes and nodes thereby allowing for underlying relationships to be examined. For example, the correlation between home ownership and the identified motives were examined using matrix coding which was made possible by the initial creation of the node classification.

Phase 2: Topical

At the topical phase, obvious topics were first identified from the transcript material and later based on previous literatures. The existing concepts guided the initial assigning of the data into nodes. This process referred to as coding is simply a code-and-retrieve procedure which involves marking and underlining relevant pieces of the transcript data (Bryman, 2012). In this analysis, a line-by-line and sentence-by-sentence coding process was followed leading to the full coverage of all the relevant issues as revealed by the adopters.

The NVivo memo tool was also useful and served as a reminder and connector of the disparate ideas that were developing as the data was being coded. The memo function allows for interconnection to be made between well-known concepts and emerging themes in a data set (O'Neil, 2013). Also, at this second stage a tentative coding was being carried out to identify evolving patterns. The preliminary coding process made use of coding stripes and highlighter to show coded areas and emergent patterns.

One advantage of this initial coding effort was to gain an idea of the response direction and to reveal the areas not fully represented in the analysis. Using the highlighter and coding stripes function, NVivo allows users to see the amount of coding already applied to respective answers to questions and the similarities and differences in the coded data. From this, trends were identified and where necessary new themes and/or nodes were created. A key advantage of the highlighter feature was that it helped to prevent multiple coding of the same piece of data. Examples of the use of coding stripes and highlights used in the interview analysis are presented in subsequent sections.

Phase 3: Analytical

A decision was made at the analytical phase as to the most frequently cited references. They included the relevant concepts being mentioned by the adopters compared to existing theories. For example, the frequent use of terms like light, blackouts, generator, expensive were signals. Recurrent references, themes and surprise statements largely influenced the coding pattern and subsequently, the hierarchy.

To facilitate the identification of new concepts, search queries were used in the form of text search and word frequency. The text search and word frequency command allows for texts to be searched by requesting say 50 or 100 most frequent texts/words in the data. Tree maps and tag clouds were used to compare the frequency of different words. Cluster diagrams and tag clouds helped to display the important references. In the former, the larger the cluster, the greater its importance in terms of frequency while in the latter larger words indicate the more frequently used words for expressing matters of concern.

Matrix coding was used to examine relationships between themes, concepts and participant socio-demographics. Models were further created to explore the similarities and differences in the coding and comparisons made with findings in existing literatures. In addition to grounded theories, word frequency, and the element of surprise, further coding decisions were made because the adopters specifically mentioned that it was important.

Phase 4: Conclusions

While much of the conclusions were readily confirmable as the analysis progressed, it was at the end of the data transcript and analysis that the findings were substantiated. The coding structure employed enabled an insightful exposition of hidden meanings. Nonetheless, conscious efforts were made to ensure that to a large extent '*what the adopters said*' was reported and not what the researcher thought they meant.

Aside the narratives used to describe and explain the interview transcript data, the 'validation procedure' largely used for comparison of the questionnaire and interview results was data transformation. Furthermore, data coding and transformation or 'quantitizing' were the data reduction techniques used in the NVivo analysis to examine emergent patterns and relationships from the study. Quantitizing is the term used to describe this act of converting and transforming analysis data into numerical values to aid this compare and contrast purpose (Borrego et al, 2009).

For example, through the use of line-by-line coding, quantitative data were generated and represented in chart and graph forms. This transformation exercise made the relevant links to appear and the relationships better explained visually. The final verification process was straightforward and involved a visual inspection of the codified nodes in relation to each adopter's contribution to the overall percentage. This was made clearer due to the transformation of the data and its representation using charts and matrix tables to illustrate key findings.

Interviewing early PV adopters was believed to be the best way to gain insight and elicit the opinions of the PV adopting households. The experience and role of the end-users will be vital either in a private PV purchase scenario or in a grid-tied supply system. This is because the experience of early adopters would determine whether PV will eventually be widely embraced in Nigeria. The early PV adopters present a more reliable research fit to help understand the slow PV diffusion rate in Nigeria. Their experiences would be central to future decentralised renewable energy developments in Nigeria. The next section details the triangulation (mixing) of the two methods.

5.6 Triangulation and rationale

Triangulation is the process of combining methodologies in the examination of the same phenomenon (Bryman, 2012) or the use of qualitative research to substantiate quantitative research and vice versa (Knight and Ruddick, 2008). An example of a triangulation is combining structured questionnaire surveys and semi-structured interviews in the same research project. Because the study examines the barriers and motives to PV uptake, the use of mixed methods was considered more appropriate. Another obvious reason for such integration is that each individual method has strengths and weaknesses. But, by integrating both methods the weaknesses are smoothened out as both aspects become mutually reinforcing. The quantitative part of this study used questionnaire surveys while the qualitative aspect relied upon interviews.

An investigation into the obstacles to PV adoption in Nigeria is one that requires an approach that goes beyond hindrances and stated or revealed preferences using the willingness-to-pay (WTP) concept. To fully comprehend the socioeconomic problems faced and the underlying issues at stake would require directly speaking and engaging the innovative PV adopters. Their version of events would verify, strengthen and give credence to the views expressed in the questionnaire. This group would have had first-hand experience. Therefore, their accounts would be purely based on their *lived experience* which is often the most reliable source of information (Creswell, 2009).

Moreover, a study that seeks to understand household energy use behaviour and intent would further benefit from a mixed approach since human actions, beliefs, views, perspectives and purchase decisions will be best captured not just by interviews but also by observing the respondents in the natural and environmental context provided. Another aspect covered in the questionnaire explored the WTP theory. Studies have shown that the responses sometimes provided to WTP questions do not always convey the actions the survey respondents will take in a real-life situation. To further improve the power and usefulness of the questionnaire responses, the interviews with PV adopting households were conceived as a means of providing additional insight to what closely matches the actual or real-life scenario. This opportunity could only be taken advantage of via mixed methods strategy.

As with other research approaches mixed methods research has faced criticism. Opponents argue that:

- Research methods carry epistemological commitments and that
- Quantitative and qualitative research methods are separate paradigms

Bryman, (2012) argues that by aligning research method with a particular epistemological position is misleading, because a researcher can, when it is considered infeasible to carry out all experiments directly on participants, choose to use questionnaires. This does not make the research qualitative nor does it reflect mixed methods. Thus, assigning an epistemology to a type of research method is baseless. Precisely, the mixed-method approach known as concurrent triangulation was adopted both during the data collection stage and at the data analysis phase. Aside providing answers to the research questions and triangulation benefits, both methods were used in this research for utilitarian purposes, to enhance results and to ensure completeness.

When correctly applied, data triangulation can give greater validity to the results, making for a more robust and reliable outcome (Creswell, 2007). In relation to completeness, a mixed methods strategy leads to a more thorough and comprehensive account of the phenomenon under study as shortcomings in each is counterbalanced by the strengths in the other. Many researchers agree that research methods should be combined when the case presents itself because theory building requires ‘hard’ data to reveal relationships and ‘soft’ data to explain these relationships (Knight and Ruddick, 2008). Enhancement was observed in some of the questionnaire results where the interview results confirmed many of the answers supplied in the questionnaire, thus reinforcing the findings. The links between the qualitative and quantitative results serve to support and justify the use of mixed methods research approaches. Lastly and most importantly, this study is strongly linked to influencing renewable energy policies in Nigeria. For this reason, a utilitarian rationale cannot be denied. Therefore, this study seeks to use the findings to aid energy policy decision makers in their design and implementation of PV support strategies for maximum private sector participation. Finally, the nature and complexity of construction projects and the built environment in general further gives credence to the utilisation of methodological pluralism as the theoretical benefits are apparent (Knight and Ruddock, 2008).

5.6.1 Priority decision of the triangulation approach

A decision had to be made regarding the ordering of the triangulation approach. That is, assigning weights and deciding which should come first in the presentation between the quantitative methods and the qualitative methods. Again, this decision was made first and foremost on the research questions posed. Because the initial question was to investigate the barriers to PV uptake by Nigerian households, the questionnaire survey (quantitative methods) was first designed. The three major aspects of triangulating data were methodically observed and applied to this study. They include decisions on sequence or weighting, mixing and theorizing of the data (Creswell, 2009; Bryman, 2012).

Weighting

The interrelationship between the initial research question and the second question (motives for PV uptake and the likely role of Government support towards influencing increased uptake) meant that the questionnaire survey and the interviews were carried out more or less simultaneously, although the interviews were last to be concluded. This was due mainly to the difficulty finding PV users. During questionnaire administration and data collection, both the questionnaire and interviews were executed concurrently. The priority and ordering or sequence decisions were thus accorded the same weight.

Mixing

At the mixing stage, the decision was made as to how the two research methods are to be combined or merged. The merging of the two research data types obtained occurred at all three points of collection, analysis and interpretation, albeit to differing degrees. However, while the research questions were the constant guide, the choice of when and how to mix the data sets was principally made to ensure uttermost clarity and comprehension of the findings more than for anything else. Since the interview results helped provide supportive information and confirmed many of the questionnaire results, it made sense for it to come after the questionnaire results explanation.

Theorising and data transformation

Lastly, a final decision that was made related to theorising and transforming of perspectives. In essence, theorising relates to the theoretical framework of the study e.g. innovation diffusion theory and the WTP concept as it impacts PV adoption. These theories were explained in detail earlier and in many ways helped shape all the data collection and analysis phases through the questions asked, the study participants selected and finally the results arrived at. Data transformation on the other hand is a data management process that allows for comparisons to be easily made as both work products are set on similar levels. For instance, in this study, some of the NVivo results were transformed by exporting the converted textual data to Microsoft Excel and using it to plot charts and tables as deemed fit. A full set of results are presented in Chapter 6.

5.7 Ethical considerations

Ethical principles of informed consent was abided by and conformed to at all times in the course of both the interviews and the questionnaire implementation. The consent form and letter of identification were shown to the questionnaire respondents before they were handed out. The cover page of the questionnaire also laid bare the purpose of the survey and a promise to protect participants' identity. As regards the telephone interviews, the adopters were informed before the interview that the conversation would be recorded using an audio device and that it was solely for research purposes. Those interviewed face-to-face were shown the letter of consent and written statement from Heriot-Watt University indicating the school's stance on matters of ethical concerns and their commitment to the privacy and protection of all respondents. The participants were assured that all the information provided would be held in strict confidence and used in ways that would not identify them. This was done in adherence to the UK government's Data Protection Act 1998.

5.7.1 Challenges, limitations and lessons learned

In the course of arranging the interviews, some challenges arose. First, an agreement had to be reached with the adopters as to the date and time for the interviews. This led to a number of phone calls in the course of scheduling these interviews. Some of the adopters requested call backs at times when the University would have closed down for the day. So as to not lose the opportunity to conduct the interview, the researcher had to resort to using personal mobile phone in such cases. However, all the telephone interviews were conducted in the university interview room for which the researcher had open access.

At other times, the inconvenience of using Heriot Watt University's telephone created some research difficulties. There were occasions when telephone connection to the control room was denied, despite repeated calls to the line, in order to be connected to adopters who were abroad. This was possibly caused by other calls to the control making it busy. These posed great challenges for the research because it sometimes meant that scheduled interviews were cancelled and the adopters contacted to apologise for the failure. Added to this was the time zone difference which created further challenges for the research. Alternative arrangements were made to combat these problems.

A key challenge of the methods and approaches taken in this study was the volume of data generated and the time intensive nature of utilising triangulation. But it can be very rewarding and worthwhile because at the final interpretive phase, the researcher reported the meaning of the case, whether that meaning comes from learning about the key issue of the case (an instrumental case) or learning about an unusual situation (an intrinsic case). It is this interpretive phase that constitutes the "lessons learned" (Borrego et al, 2009) which is the basis of every research.

5.8 Summary and conclusions of the research methodologies

This chapter has discussed the methods, strategies and techniques used in this study. The questionnaire examined consumer stated obstacles and WTP. It should be noted that the major purpose of the interview was not to evaluate the hindrances to PV adoption. However, the overlap and interrelationship between the motives and barriers meant that the recording of one without the other would be impossible. In a sense, the motives for and hindrances to PV uptake are two sides of the same coin. Also, the sometimes emotional attachment Nigerian households' hold of the power supply problem meant that one could not be dealt with without the other. Nevertheless, the researcher remained sensitive to the distinction between concepts, categories and emerging trends that developed through continuous revision of the transcript data.

Employing both quantitative and qualitative research methods signifies taking an all-round approach which ensured that both the needs of the research and that of the energy end-users were catered for. Through the constantly evolving process of coding, frequent comparisons and finally theoretical saturation, grounded theory research creates concepts and categories that could lead to substantive and formal theories. This chapter has elucidated on the research methods used in the study and the justification for the decisions taken. The following Chapter 6 presents the results of both the questionnaire survey and the interviews. The interpretations and discussion of the collective findings are presented in Chapter 7. In Chapter 8, the combined findings and the policy analysis best practice identified in Chapter 4 is used to design a verified model for rapid PV diffusion in Nigeria.

Chapter 6

6.1 Questionnaire survey and interview results

This chapter presents the collective results of the research. The study investigated the determinants of household-level PV adoption and the likely role of government incentives towards acting as an influencer. The first part of the results is from the questionnaire survey which intrinsically focused on the barriers to PV uptake and household valuation of PV. This is followed by the interview results which essentially addressed the motives for uptake by the current small minority of users.

Literature illustrates factors influencing consumer response to PV adoption in 3 major ways. On one end is sociodemographic factors, on the other is attitudinal and behavioural constructs. Somewhere in the middle are economic paradigms. Having earlier shown how the demand for and supply of energy can be affected by a number of these factors including age, consumer values and socio-demographics, this section begins with the household characteristics of the questionnaire respondents.

6.2 Characteristics of the questionnaire respondents

The gender distribution of the respondents is represented in Table 6.1. The valid percent of participation was 75% for males and 25% for females.

Table 6.1 Gender of respondents

Gender

		Frequency	Percent	Valid Percent	Cumulative %
Valid	Female	50	25.0	25.0	25.0
	Male	150	75.0	75.0	100.0
	Total	200	100.0	100.0	

Since the questionnaire was designed for the heads of households to complete, this outcome was expected, as males are traditionally heads of households in Nigeria.

In relation to age, the questionnaire results showed a good mix across age groups. However, persons aged 31-44 make the bulk of the age distribution representing 53.5% of the sample as reflected in Table 6.2. The age group 45-64 followed with 29% of the total count.

Table 6.2 Age group of respondents

Age groups

		Frequency	Percent	Valid Percent	Cumulative %
Valid	18-30	29	14.5	14.5	14.5
	31-44	107	53.5	53.5	68.0
	45-64	58	29.0	29.0	97.0
	65 & over	6	3.0	3.0	100.0
	Total	200	100.0	100.0	

In terms of education, quite a large number of the households reported having a university degree and postgraduate qualifications as detailed in Table 6.3 below.

Table 6.3 Highest level of education attained by respondents

Highest level of education

		Frequency	Percent	Valid Percent	Cumulative %
Valid	1.00 Postgraduate	170	85.0	85.4	85.4
	2.00 Undergraduate	22	11.0	11.1	96.5
	3.00 Secondary school	6	3.0	3.0	99.5
	5.00 Informal education	1	.5	.5	100.0
	Total	199	99.5	100.0	
Missing	System	1	.5		

Though a significant number of households revealed having a university degree, there does not seem to be a considerable difference in the level of education between genders at postgraduate level, as illustrated in Figure 6.1. However, males appear to have more university postgraduate qualifications than females. This may be due to the fact that there were more male heads of households than females in the survey. In the absence of reliable statistics on national postgraduate qualifications to help ascertain representativeness of findings, the adult literacy rate data was used. National overall adult literacy of 71% with highest literacy rate reported for urban areas in 2011. In particular, Lagos state was shown to have adult literacy of 87.7% (Nigerian Bureau of Satistics, 2016) which is relatively close to the findings from this study.

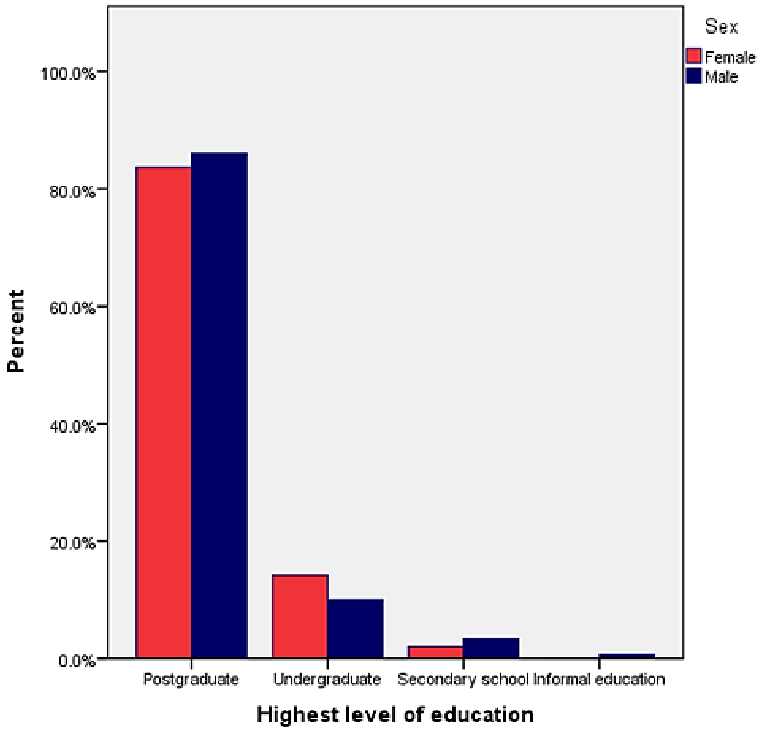

Figure 6.1 Bar graph of education level by gender

Another variable of interest used in determining the factors necessary for residential level PV adoption in Nigeria was household income. The annual amount was requested, but for ease of description, this was broken down into monthly earnings[22]. Table 6.4 illustrates.

Table 6.4 Respondents average monthly income

Average monthly income

		Frequency	Percent	Valid Percent	Cumulative %
Valid	1.00 Less than ₦83250	28	14.0	14.3	14.3
	2.00 ₦83250 - ₦250000	56	28.0	28.6	42.9
	3.00 ₦250000- ₦416500	50	25.0	25.5	68.4
	4.00 ₦416500- ₦833250	31	15.5	15.8	84.2
	5.00 ₦833250 – ₦1.7m	21	10.5	10.7	94.9
	6.00 More than ₦1.7m	10	5.0	5.1	100.0
	Total	196	98.0	100.0	
Missing	System	4	2.0		
Total		200	100.0		

[22] The exchange rate as at the time of this study was ₦250 to £1

As earlier demonstrated, income is an important factor in PV investment decision. The above income distribution indicates that close to 60% of surveyed households earned over ₦250,000 (£1000) a month. The proportion of what can be described as high income can be seen from over 31% of the households. Income earners above ₦416,500 (£1666) per month can be effectively referred to as the upper band, especially for a developing country. Figure 6.2 boxplot points to a median annual income range of between ₦3- 5m (£12000-20000).

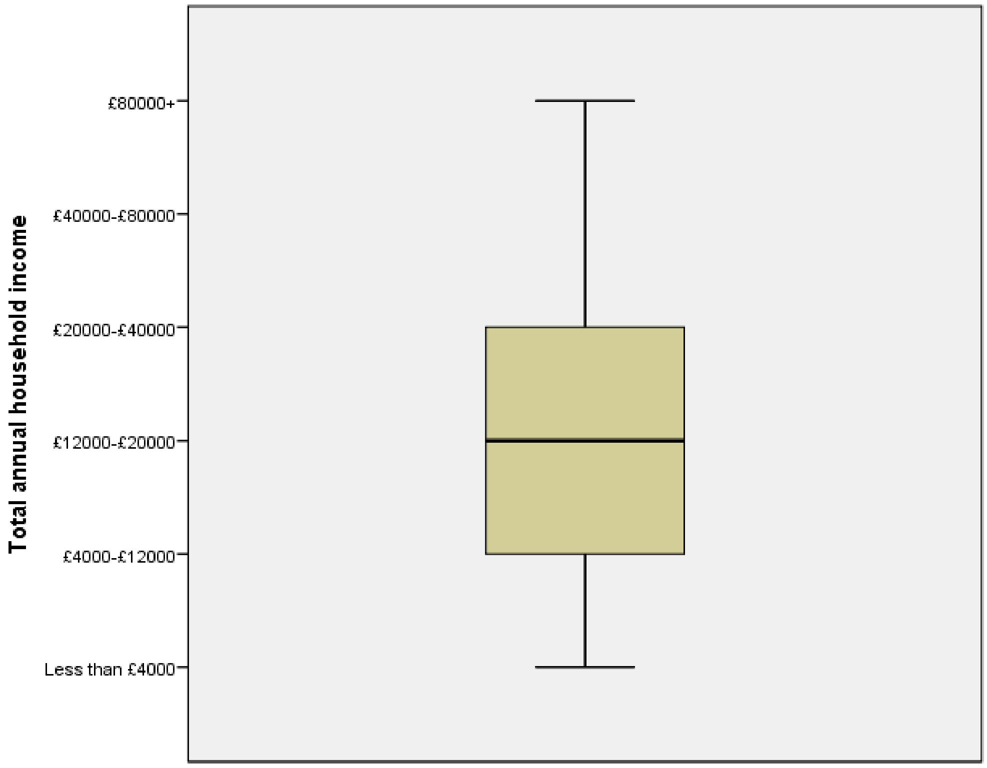

Figure 6.2 Boxplot of median annual income

The boxplot is made up of the middle 50% of the surveyed households' income. The households who earn the most income fall on the boxplot line at the top, while those earning less than ₦1m (£4000) a year is represented by the boxplot whisker line at the bottom of the plot. Reliable data could not be found on national income statistics hence representativeness cannot be ascertained. Given that many households generate income from a number of sources, it is likely that it can be higher or lower than found in this study. Hence, findings on income should be used and interpreted with caution.

6.2.1 Household size, home ownership, dwelling type and age of dwelling

The average household size given was four persons, representing 55% of the total sample and falls under the classification referred to in this study as medium-sized family. This category refers to households with a total number of 3 to 4 persons. The small family refers to households with less than 3 individuals, while a large family were those with over 4 individuals in a dwelling. Table 6.5 below is the recoded household size grouping. Also, of the families surveyed, 23% said they had one child under the age of 17 and 57% reported having 2 or more children less than 17 years of age. The typical house size was 3-4 bedrooms.

Table 6.5 Household type classification

Household type classification

		Frequency	Percent	Valid Percent	Cumulative %
Valid	1.00 Small family	110	55.0	55.0	55.0
	2.00 Medium sized family	53	26.5	26.5	81.5
	3.00 Large family	37	18.5	18.5	100.0
	Total	200	100.0	100.0	

Aside household size, another interesting finding is the rate of home ownership revealed by the study. As Table 6.6 shows almost 40% of the sampled population reported owning their own homes. Of this total 25% were self-built and 10% said they purchased outright from property developers and 1% owned through mortgage. A higher proportion (63%) reported renting their homes. 35% home ownership found in Lagos represents 53% of national home ownership (Nigerian Bureau of Satistics, 2016).

Table 6.6 Home ownership/housing tenure

Housing tenure

		Frequency	Percent	Valid Percent	Cumulative %
Valid	1.00 Self-built	49	24.5	24.6	24.6
	2.00 Purchased	20	10.0	10.1	34.7
	3.00 Mortgage	2	1.0	1.0	35.7
	4.00 Renting	127	63.5	63.8	99.5
	5.00 Inherited	1	.5	.5	100.0
	Total	199	99.5	100.0	
Missing	System	1	.5		
Total		200	100.0		

A feature of home ownership that was not highly reported was inherited dwellings. Only 1 individual said his home was acquired through inheritance[23]. This was an open question requiring that respondents state any other source(s) of home acquisition so may have been under reflected.

In addition, dwelling types were assessed. Households who lived in duplexes and bungalows made up the second and third largest category in the property types, next only to households who lived in flats (53%). Thus, all other things being equal, a majority of the dwelling types are suitable for mounting PV modules. However it is important to note that for dwelling types such as flats there may be roof-space limitations due to roof-size and issues of multi-occupancy which could mean that PV installations in such dwellings be ground mounted taking into consideration the practical constraints and security risks this presents.

Table 6.7 Dwelling type

Property type

		Frequency	Percent	Valid Percent	Cumulative %
Valid	1.00 Duplex	33	16.5	16.6	16.6
	2.00 Bungalow	27	13.5	13.6	30.2
	3.00 Detached house	17	8.5	8.5	38.7
	4.00 Semi-detached	8	4.0	4.0	42.7
	5.00 Terraced house	4	2.0	2.0	44.7
	6.00 Flats	107	53.5	53.8	98.5
	7.00 Self-contained room	3	1.5	1.5	100.0
	Total	199	99.5	100.0	
Missing	System	1	.5		
Total		200	100.0		

Also of relevance was the age of the respective dwellings. Most (52%) were built in the last decade, and a further 21% constructed in the last 15 years. The respondents were also asked of their likelihood of moving home in the next ten years using a 5-point Likert rating scale. Table 6.8 represents the responses which indicated a very high likelihood of relocation at 58%.

[23] This should not be taken to imply that few people acquire their homes via inheritance because the response was not included in the questionnaire list of options.

Table 6.8 Likelihood of moving home

Likelihood of moving home

		Frequency	Percent	Valid Percent	Cumulative %
Valid	1.00 Not at all likely	31	15.5	15.5	15.5
	2.00 Slightly likely	29	14.5	14.5	30.0
	3.00 Neutral	23	11.5	11.5	41.5
	4.00 Quite likely	42	21.0	21.0	62.5
	5.00 Extremely likely	75	37.5	37.5	100.0
	Total	200	100.0	100.0	

6.2.2 Electricity supply and energy use

So as not to falsely assume that all the surveyed respondents found their central power supply unsatisfactory, it was considered necessary to enquire about the general level of household satisfaction with grid electricity. As revealed in the pie chart, about 90% of the households said they were dissatisfied with grid power. All but one household reported not being affected by power outage. The reason was that they were not connected to the grid network in the first place. But most households shared their disappointment, with some adding remarks on the questionnaire explaining the standing charges plus exorbitant energy bills they pay without receiving commensurate level of supply.

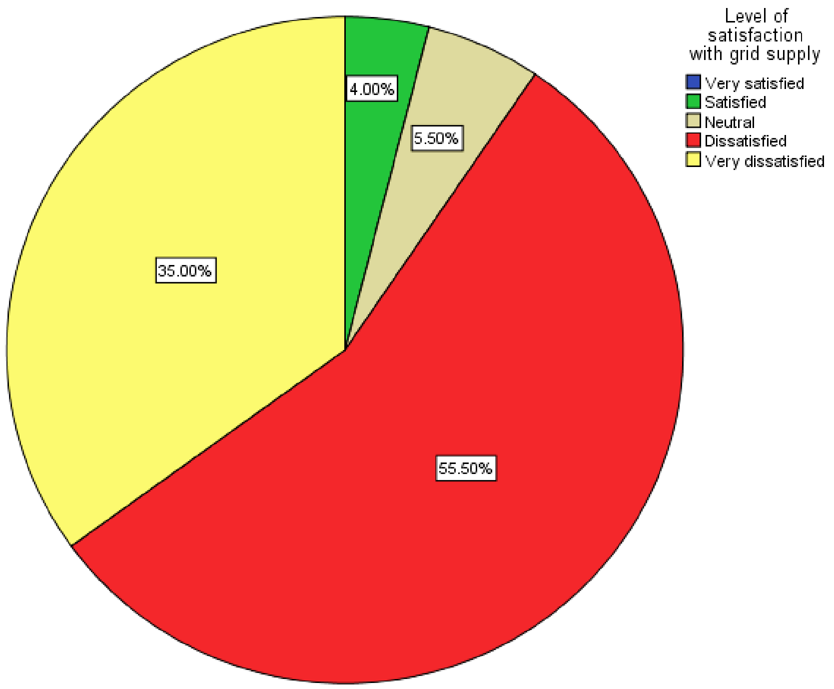

Figure 6.3 Level of grid power supply satisfaction

Further probing showed that the average level of central electricity supply received per day was 6 hours. Fewer individuals felt they received a fair share compared to the rest of society and were relatively satisfied with the central network. Many in this group stated that they received more than 8 hours of daily grid electricity supply. Table 6.9 provides detail. This question was crucial for assessing household likely interest in PV generated power.

Table 6.9 Mean daily grid power supply

	Average daily grid supply bands				
		Frequency	Percent	Valid Percent	Cumulative %
Valid	0 0 hour	2	1.0	1.0	1.0
	1 1-3 hours	39	19.5	19.5	20.5
	2 3-5 hours	37	18.5	18.5	39.0
	3 5-7 hours	37	18.5	18.5	57.5
	4 7-10 hours	32	16.0	16.0	73.5
	5 10 hours+	53	26.5	26.5	100.0
	Total	200	100.0	100.0	

Regarding the alternatives used to supplement grid shortages, 85% relied on petrol generators. Of this, 24% reported having diesel-operated generators. These are often larger (>4kVA) power systems and more expensive. Many used a combination of alternative lighting system to sustain themselves during power outages with 15% stating that they also used candles and rechargeable lamps and torchlights. 24% said they still used kerosene lamps. About 7% said that they made use of solar PV. A lesser number (4%) reported relying on inverter.

The high usage of private generators was expected. Further enquiries revealed that the households spent a considerable amount on the use and maintenance of these power systems. About 30% of households spent ≥ ₦25000 per month on self-generation. 48% spent between ₦10000-25000 while 22% spent ≤ ₦10000 on private generation.

The expenditure on petrol and diesel self-generation was found to be associated with variables such as households' age, income and home ownership. For example, the chart below reflects the association between monthly generator use expenditure and age. As can be observed in the chart, generator use expense is related to age. Individuals under 30 years spent the least amount each month. Most expenses between ₦12500-35000 per month were made by individuals aged 31-44 years. Households from age 45-64 incurred the most expense (≥ ₦50000) each month. Overall, individuals aged 65+ appeared to be less involved in auto-generation.

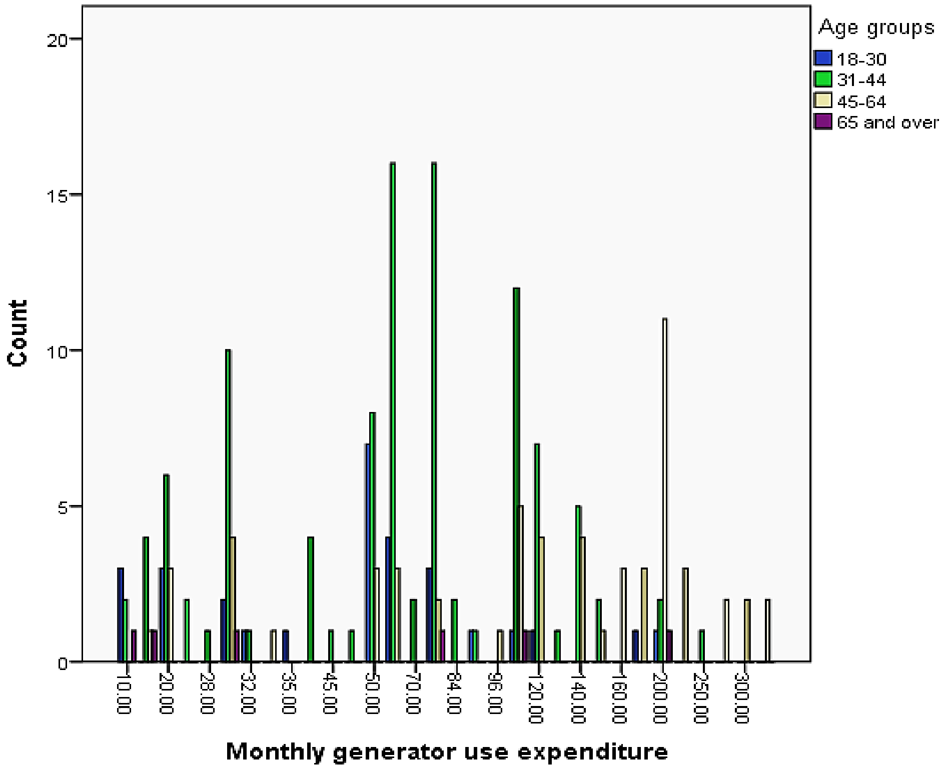

Figure 6.4 Correlation between age and monthly generator use expenditure

Income was also shown to be related to amount spent on generator use as reflected in Figure 6.5, with individuals who earned above £12,000 (₦3,000,000) per annum spending over £80 (₦20,000) each month.

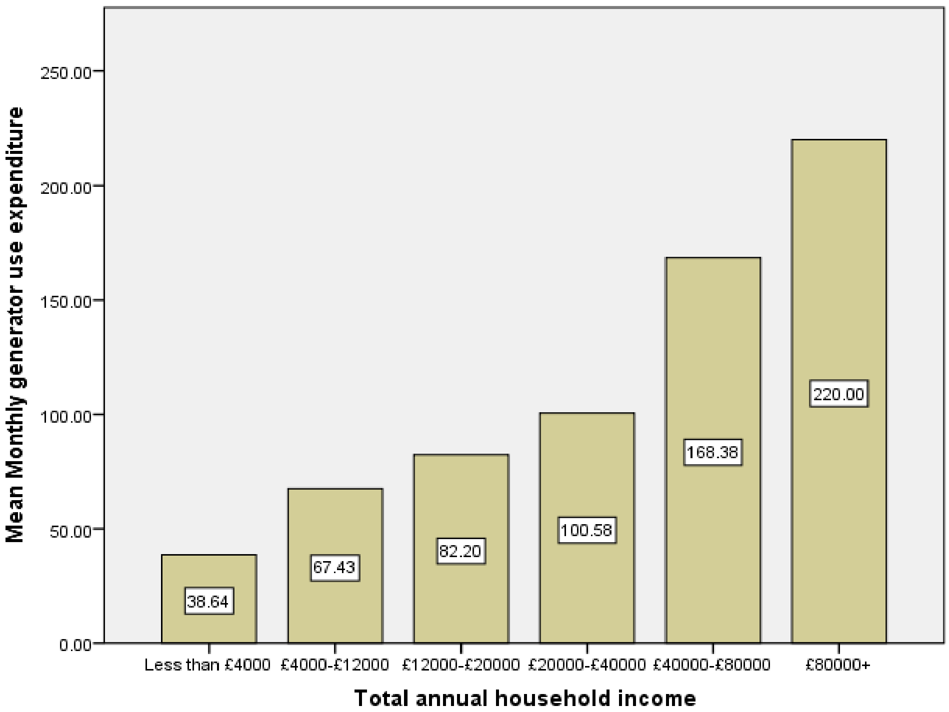

Figure 6.5 Correlation between income and monthly generator use expenditure

To investigate whether households will be receptive to PV it was necessary to ask if they would be WTP additional charges for improved grid electricity and by how much. Of those who it pertained to, responses pointed to a high WTP a premium for better grid services as shown in Figure 6.10. Although 86% of the households said they were WTP a higher amount, about 41% said they would be prepared to pay between 10-25% increases in electricity costs. Surprisingly, 17% said they were ready to pay anything between 25-50% more for improved services. Only 3% said they would pay greater than 50% rise in electricity costs. However, few individuals said they were unwilling to pay, citing inaccurate billing and high energy tariffs as reasons. Others purposely built their homes without connection to the grid power lines and mentioned plans to live off-grid using solar.

Table 6.10 WTP a premium for improved grid supply

		Frequency	Percent	Valid Percent	Cumulative %
Valid	1.00 Less than 10%	68	34.0	39.3	39.3
	2.00 10-25%	71	35.5	41.0	80.3
	3.00 25-50%	29	14.5	16.8	97.1
	4.00 50-75%	3	1.5	1.7	98.8
	5.00 100% plus	2	1.0	1.2	100.0
	Total	173	86.5	100.0	
Missing	9.00 Not applicable	26	13.0		
	System	1	.5		
	Total	27	13.5		
Total		200	100.0		

6.2.3 Knowledge of environmental issues and energy conservation efforts

Studies indicate that knowledge of environmental issues can influence energy choices. To measure household awareness of environmental sustainability and knowledge of the impact of fossil fuel reliance on the environment, few questions requested this information. The perception of the impact of fossil fuel use on global warming was measured through a rating scale and showed that 54% of the households viewed fossil fuel exploitation as responsible for global warming effects.

With regards to their environmental consciousness they were requested to self-assess. Results indicated that almost half (47%) of the respondents believed they were environmentally aware, 7% said they were not, while 46% were unsure. Likewise, a very high proportion of households did not engage in environmental habits such as recycling (95%) and the use of public transport (63%). Most households (75%) stated boiling only the required water.

In addition, regarding energy use and conservation measures, the responses were varied but presented an above average level of energy management by the households. About 78% said they used energy saving lightbulbs and switched off lights when not in use. There was also a high level of energy bill checks with 66% saying they checked bills received at least once every month, 20% said they did week/biweekly checks of energy consumption. Others checked infrequently with 6% saying they did not engage in these checks.

6.2.4 Solar PV awareness

PV awareness and familiarity precedes adoption. In order to determine if households would be willing to consider a switch to a better alternative, it was necessary to find out if they were aware of PV energy in the first instance. Households were initially asked if they know or have heard of solar PV and their sources of information. Table 6.11 points to a very high level of PV awareness amongst the households.

Table 6.11 Household PV awareness

Solar PV awareness

		Frequency	Percent	Valid Percent	Cumulative %
Valid	0 No	15	7.5	7.5	7.5
	1 Yes	185	92.5	92.5	100.0
	Total	200	100.0	100.0	

Similarly, the following Figure 6.6 is an illustration of the diverse mediums by which households came to know about solar PV. TV/radio, print media and billboards advertising seemed to be the most important source of awareness creation. Next to this were building roof and the internet representing about 90%. Promotion campaigns were less reported than word of mouth (neighbour PV usage) as an awareness source. Remarkably, SPSS case summary tests later conducted also confirmed that of the PV users, 77% had a neighbour or knew someone who used PV.

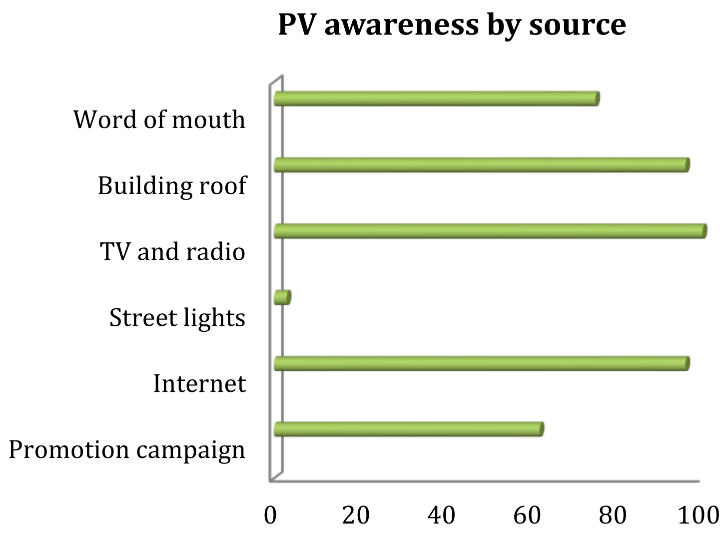

Figure 6.6 PV awareness by source

6.2.5 Household perception of solar PV

The perception of PV in terms of relative advantage, complexity and compatibility as given by Rogers (1991) was examined. This assessed views on PV costs, payback time (PBT), efficiency and how compatible it was believed to be with the households' lifestyles. In relation to costs, 82% perceived PV to be too expensive but 18% disagreed. Regarding efficiency, 44% also thought it was efficient but 6% said it was an unreliable technology. Half of the respondents were unsure. In terms of PBT over 74% of the respondents showed a preference for the shortest time of 10-12 years.

Other factors that could constitute a barrier to household PV uptake were examined. Less than 7% thought that PV installation was inconveniencing and could damage their property. Most were home owners. Findings also indicated that 46% did not view PV installation as likely to affect their building. In fact, a majority (68%) were of the opinion that residential PV would increase the value of their homes, as they anticipated future development and value of PV systems. In addition, 40% thought PV would be easy to use and hence compatible with their existing system and lifestyle.

Results further showed that 51% of the households would hesitate to install PV single-handedly without any form of support incentives as Table 6.12 depicts. The responses to the strongest drivers for such self-help action of installing PV in the absence of incentives, revealed that power outages (70%) were more of the motive than environmental concerns (30%).

Table 6.12 Willingness-to-pay (WTP) for PV without aid

WTP for PV without any aid

		Frequency	Percent	Valid Percent	Cumulative %
Valid	.00 No	102	51.0	51.0	51.0
	1.00 Yes	98	49.0	49.0	100.0
	Total	200	100.0	100.0	

When presented with forms of fiscal support for PV investment, a higher preference was shown for bank loans and import duty cuts compared to tax rebates. 41% showed interest in bank loans but the percentage of those who would not consider taking bank loans were much higher (59%). About 31% preferred import duty cuts. The least preference was shown for tax cuts and VAT exemptions at 10%.

The role of incentives towards influencing PV diffusion is widely acknowledged. Results in this study also support this theory, as when discounts in the form of Government incentives were offered, the household acceptance of PV increased significantly to 87% as can be seen in Table 6.13. From the cumulative answers to the WTP elicitation question, the most preferred amount of subsidy was one that gave 50-60% discount off total costs (Figure 6.7). However, any discount from 30% to 60% would yield meaningful patronage for PV.

Table 6.13 WTP for PV with aid

Government subsidy as a motive for PV adoption

		Frequency	Percent	Valid Percent	Cumulative %
Valid	0 No	25	12.5	12.9	12.9
	1 Yes	169	84.5	87.1	100.0
	Total	194	97.0	100.0	
Missing	System	6	3.0		
Total		200	100.0		

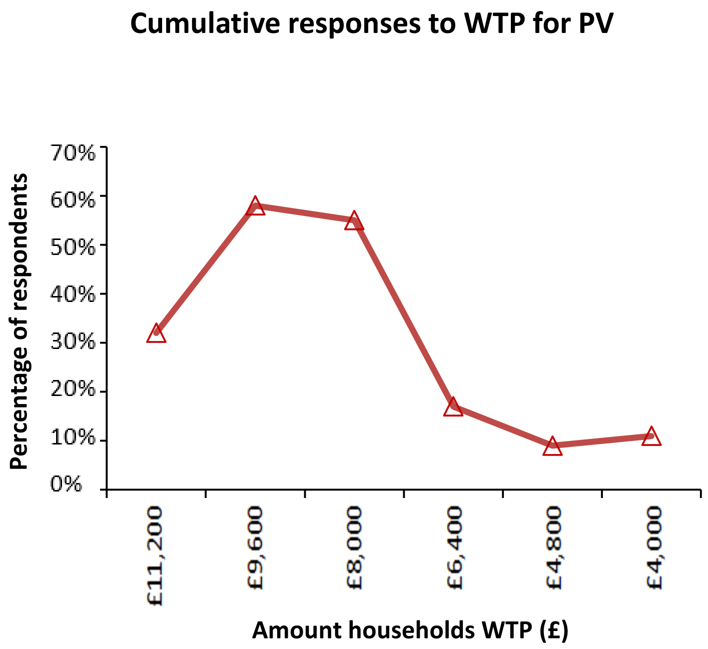

Figure 6.7 Cumulative household WTP responses to the elicitation question.

Grid-connection would be central to increase national generation capacity. The response to whether households would grid-tie if such services became available was more affirmative (72%) as shown in Table 6.14.

Table 6.14 Willingness to grid-connect

Willingness to grid-connect and export surplus

		Frequency	Percent	Valid Percent	Cumulative %
Valid	0 No	53	26.5	27.5	27.5
	1 Yes	140	70.0	72.5	100.0
	Total	193	96.5	100.0	
Missing	System	7	3.5		
Total		200	100.0		

This finding was encouraging as it helps to foresee the likely consumer reaction towards grid integration which is a key aspect of modern self-generation systems.

Other relevant relationships explored at this point were the links between respondents WTP and age, gender and home ownership. The purpose of the association in the line graph in Figure 6.8 was not to distinguish WTP between males and females. It was primarily to show the association with respect to age and amount the respondents were prepared to pay. Age and income are prime factors impacting household-level PV adoption. The interesting results clearly demonstrate a higher PV valuation as a function of increase in age. Individuals aged 18-30 were less WTP more than ₦1.5m (£6,000) for a hypothetical 5kWp PV system costing ₦4m (£16,000). There was a remarkable rise in WTP from ages 31-44. However, the mean average WTP was ₦2m (£8000).

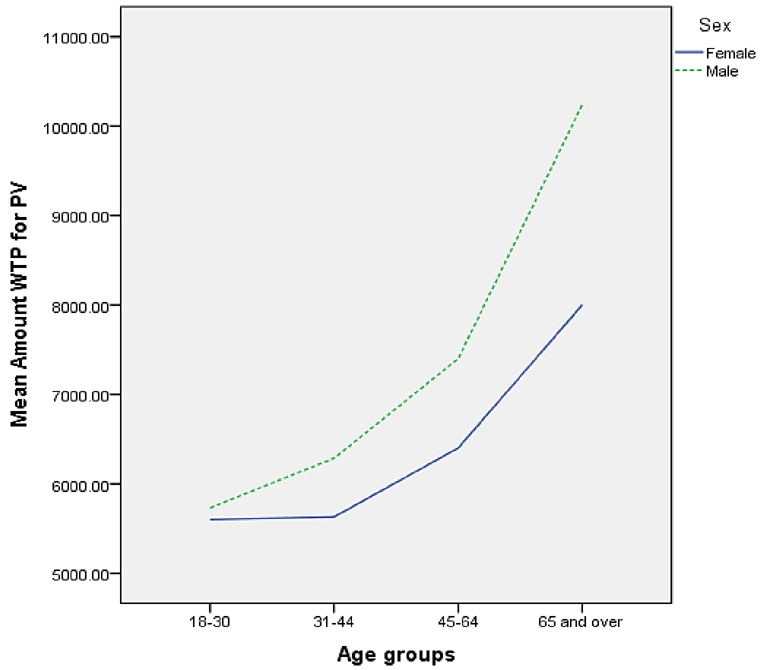

Figure 6.8 Mean WTP for PV by age and gender

6.3 Correlation results

Table 6.15 presents the Spearman's correlation matrix for the WTP for PV as the depended variable and the hypothesized barriers and household characteristics as the independent variable. Most barriers correlate with household WTP for PV significantly ($p < 0.01$) with the expected signs. Predictably, levels of electricity supply received (power outages), finance, PBT, quality of PV products, costs of low energy appliances, house move, perception of costs and efficiency all shared a strong correlation with PV valuation.

Regarding socio-demographic factors, age showed a positive correlation with WTP for PV at $r = .162$, $p < 0.05$. This means that there is a direct relationship between age and an individual's valuation of PV. As expected, income positively correlated with WTP ($r = .142$, $p < 0.05$) but represents the weakest correlation. This direct correlation implies that the more income a household earns, the greater the likelihood of adopting PV. Similarly, income also correlates strongly with age ($r = .436$, $p < 0.01$) and home ownership ($r = .397$, $p < 0.01$).

Housing tenure (home ownership) showed an underlying relationship with the willingness to adopt PV technologies ($r = .182$, $p < 0.05$). Using the coefficient of determination construct in regression analysis, this indicates that about 16% of the variance in housing tenure can be explained by income[24]. Logically, home ownership also correlates highly with age at $r = .406$, $p < 0.01$.

Furthermore, education has a negative correlation with household valuation of PV ($r = -.180$, $p < 0.05$), hinting on an indirect link between the level of education attained and PV purchase decision. In this sense, education level attained does not necessarily determine PV uptake. Thus, the variables from the socio-economic classifications that yielded significant correlations with PV adoption were age, education, household income and home ownership. Gender did not appear significant.

[24] To arrive at this figure the value of *r* is squared.

Table 6.15 Correlation between variables

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1 WTP for PV	1.000																			
2 Gender	.097	1.000																		
3 Age	.162*	.151*	1.000																	
4 Household size	.032	.224**	.404**	1.000																
5 Home ownership	.182*	.018	.406**	.466**	1.000															
6 Age of dwelling	.132	.002	.091	.104	.038	1.000														
7 Average monthly income	.142*	.105	.436**	.281**	.397**	-.097	1.000													
8 Level of education	-.180*	-.024	-.109	.011	-.047	.208**	-.165*	1.000												
9 Daily power supply hours	-.301**	-.067	.090	-.096	.053	-.196**	.214**	-.159*	1.000											
10 Planning permission	-.039	.026	.148*	.070	.152*	-.091	.157*	-.124	.256**	1.000										
11 Finance	-.294**	-.024	.023	.045	-.128	-.133	-.026	-.090	.180*	-.029	1.000									
12 Product quality	.185**	.162*	-.050	.059	-.063	.047	-.021	-.005	-.190**	-.118	-.216**	1.000								
13 Fear of damage to home	.058	-.019	-.155*	.026	.084	.002	.052	.144*	-.158*	-.070	-.362**	.001	1.000							
14 Payback time	.360**	.019	.066	-.012	.131	.225**	-.011	-.039	-.168*	-.268**	-.225**	-.077	-.076	1.000						
15 Roof space	.071	.010	.157*	.140*	.190**	.030	.176*	.173*	-.033	-.147*	-.102	-.019	-.042	-.087	1.000					
16 Inconvenience	.159*	.045	-.044	-.029	.118	-.095	-.050	.010	-.086	-.126	-.233**	-.103	.066	.146*	-.055	1.000				
17 House move concerns	-.327**	-.111	-.141*	-.193**	-.256**	-.076	-.139	.007	.167*	-.390**	.126	-.234**	-.047	-.195**	-.126	-.147*	1.000			
18 Perception initial cost	.209**	-.006	-.091	.079	.007	.222**	-.273**	.078	-.492**	-.201**	-.202**	.196**	.158*	.196**	-.146*	.138	-.211**	1.000		
19 Perception efficiency	-.195**	-.074	-.052	-.075	-.117	.115	-.067	.082	.173*	.050	-.005	.130	-.078	-.110	.104	-.207**	.091	.026	1.000	
20 Use of low energy appliances	-.188**	.064	.094	-.077	-.047	-.228**	.235**	-.149*	.486**	.287**	.211**	-.125	-.114	-.140*	-.011	-.042	.081	-.396**	.117	1.000

*$p < 0.05$; ** $p < 0.01$ Note: Note: * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

6.3.1 Barriers to PV adoption

A notable finding that helps to explain the slow private-sector PV investment in Nigeria is the hours of electricity supply received on a daily basis. Described here as power outages, the results indicate that the degree of power outages shares a negative correlation with WTP for PV (r = -.301, $p < 0.01$). By implication, households who received higher levels of grid power supply were less inclined to invest in PV systems. In other words, households who received lower levels (< 6 hours) of central power supply placed higher value for PV because they were the most affected by power outages. The levels of power supply received also revealed some correlation with income (r = .214, $p < 0.01$). Generally, the areas with longer hours of grid electricity are more affluent and hence often occupied by individuals of higher social status.

Of particular importance is the negative correlation between finance and WTP (r = -.294, $p < 0.01$). This indirect correlation implies that the absence of or lower the support incentives, the less willing householders are towards installing PV. Clearly, household concerns about the high initial cost of PV in the absence of financial support are a deterrent to uptake.

As would be expected, the availability of quality products is also positively correlated to WTP (r = .185, $p < 0.01$). The better the perspectives on the quality of PV modules being marketed, the higher the likelihood of uptake. Thus, the more households perceive PV to be of poor quality, inefficient and unreliable, the less likely they are to pay as confirmed by the negative correlation between perception on efficiency and WTP (r = -.195, $p < 0.01$).

Furthermore, although installation inconvenience was shown to correlate with adoption (r = .159, $p < 0.05$), it was the second weakest correlation. Households who thought that the installation would be inconveniencing are less inclined to pay for PV. There is also a negative correlation with perceived installation inconvenience and the financial implication of PV investments (r = -.233, $p < 0.01$). This indirect association is easily comprehended considering the general view about the high upfront cost of PV. It is reasonable to expect that an individual who considers PV installation on their home as too much inconvenience will also criticize it as being too expensive.

Concerns about future house move appeared important in the relationship with PV purchase behaviour as shown by the correlation (r = -.327, $p < 0.01$). The individuals, who thought they were going to move home or thought house move was very likely, showed lower propensity to pay. The perception householders have of the cost of PV is a barrier and impacts buying decision (r = .209, $p < 0.01$). This perception of PV costs revealed a negative correlation with income (r = -.273, $p < 0.01$) and a positive correlation with the age of dwelling (r = .222, $p < 0.01$). Thus, lower income households have a higher than average likelihood of perceiving PV to be expensive while the older the dwelling, the lesser the inclination to incorporate PV in a home.

Another remarkable finding was the link between perceptions of PV costs and the level of electricity supply received (r = -.492, $p < 0.01$). This association points to households who receive higher grid electricity supply as perceiving PV to be too costly. With a shared variance of about 24%, this strong but indirect correlation can help explain why households in societies where power outages are infrequent are largely non-responsive towards PV adoption.

However, surprisingly, the use of low energy appliances showed negative correlation with WTP for PV (r = -.188, $p < 0.01$). This means that households who utilise energy saving devices such as lightbulbs are less likely to patronise PV. The obvious reason is that energy saving appliances are generally more costly compared to their conventional counterparts. The associated high costs of most energy saving devices can serve to deter knowledgeable investors who understand the need to utilise such energy efficient devices when PV is installed. For potential consumers who are not familiar with PV systems, this creates an additional barrier.

The next section details the results of the interviews which focused chiefly on the motives for PV adoption, problems faced by the adopters and the energy saving potential of PV. The profile of the PV adopting households is first presented in Table 6.16. The country map in Figure 6.9 shows areas where the interviewed adopters were found.

Table 6.16 Profile of the interviewed PV Adopters

Adopter	Age group	Education	Tenancy	State	PV size	Time of ownership	Period of use	Use PV put to	Occupation
B.C	35-44	Degree	Renting	Delta	350 Watts	8 months	> 6-12 months	Business	Electrical Engineer
D.T	35-44	Degree	Renting	Lagos	1.2kWp	4 years	> 2-4 years	Business	Electrical Engineer
D.S	35-44	Degree	Owner occupied	Lagos	1.6kWp	4 years	> 2-4 years	Home	Other services
D.F	55-64	Degree	Owner occupied	Abuja	5.2kWp	1 year	1-2 years	Business	Other services
D.B	25-34	Secondary	Renting	Lagos	Unknown	1 year	3 months	Business	Other services
F.I	45-54	Degree	Renting	Lagos	6kWp	1 year	1-2 years	Both	Semi-professional
F.F	35-44	Secondary	Renting	Lagos	4kWp	3 years	> 2-4 years	Business	Semi-professional
J.A	35-44	Degree	Owner occupied	Lagos	2.5kWp	2 years	1-2 years	Home	Electrical Engineer
L.S	35-44	Degree	Renting	Abuja	4kWp	2 years	1-2 years	Home	Other services
R.C	55-64	Degree	Owner occupied	Abuja	8kWp	18 months	1-2 years	Home	Other services
B.R	45-54	Degree	Owner occupied	Edo	Unknown	2 years	6 months	Home	Other services
S.A	35-44	Secondary	Owner occupied	Edo	3.5kWp	6 months	> 6-12 months	Both	Other services
S.I	25-34	Degree	Owner occupied	Abuja	2.8kWp	4 years	> 2-4 years	Both	Electrical Engineer
S.B	45-54	Degree	Renting	Lagos	2kWp	1 year	1-2 years	Business	Semi-professional

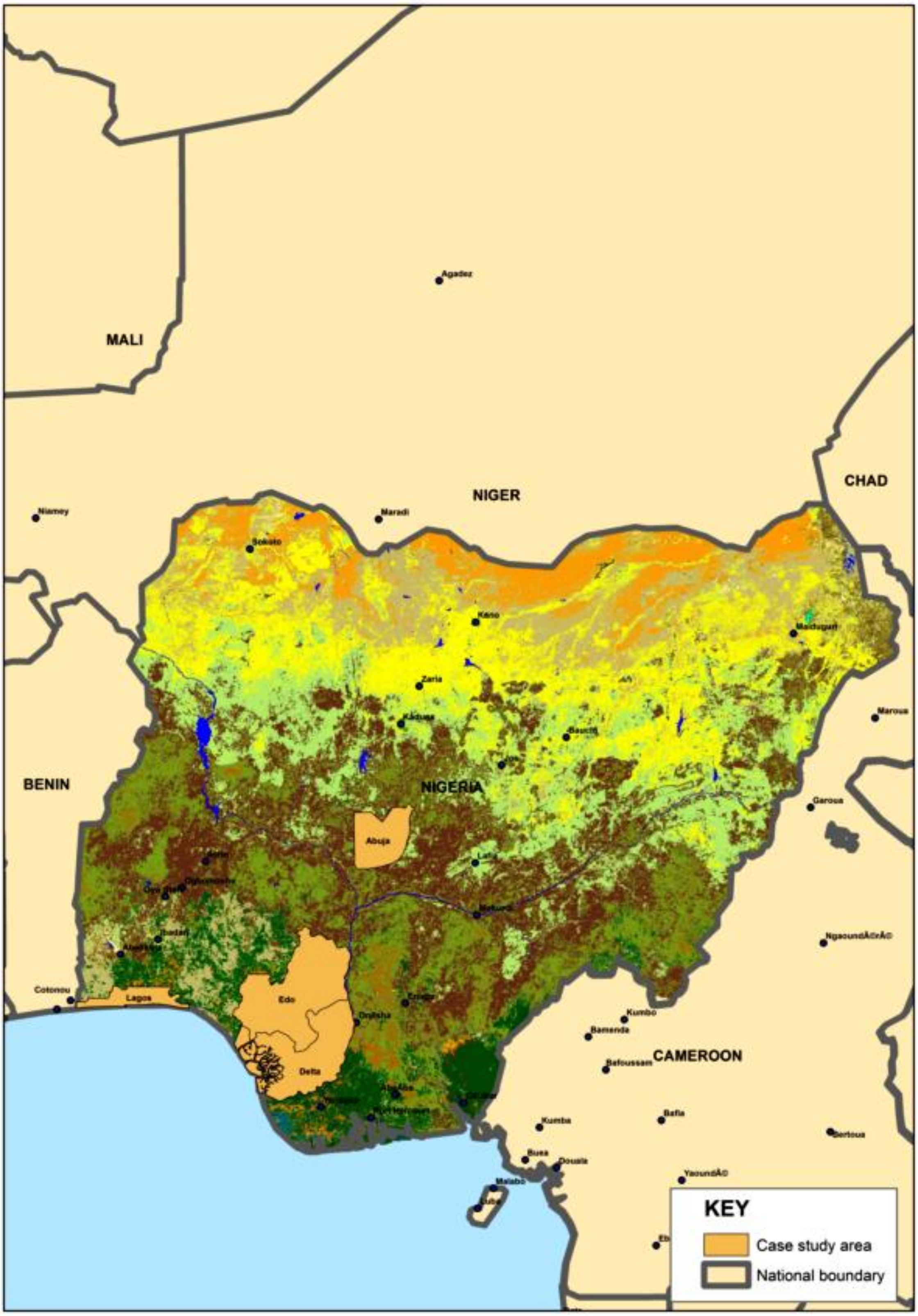

Figure 6.9 Country map of 4 cities where the PV adopters were drawn from.

6.4 Interview Results

NVivo analysis software was used to examine and identify the key factors driving PV adoption in Nigeria. This section presents the findings from the viewpoints and experiences of the households who have already installed them. While many of the results were largely consistent with reports in earlier studies, some new findings are reported here.

6.4.1 Motives for PV Adoption

- **Power outages and PV reliability**

The most significant motivation for PV adoption in Nigeria pointed towards power outages and desire for a more reliable power source. The frequency of blackouts and power failures from an unstable grid received the most reference in the interviews representing 80% of the adoption motives. The tree map in Figure 6.10 and the bar chart in Figure 6.11 illustrates. The larger the boxes in the tree map, the higher its importance. The colour coding is used to differentiate the various themes and motives identified.

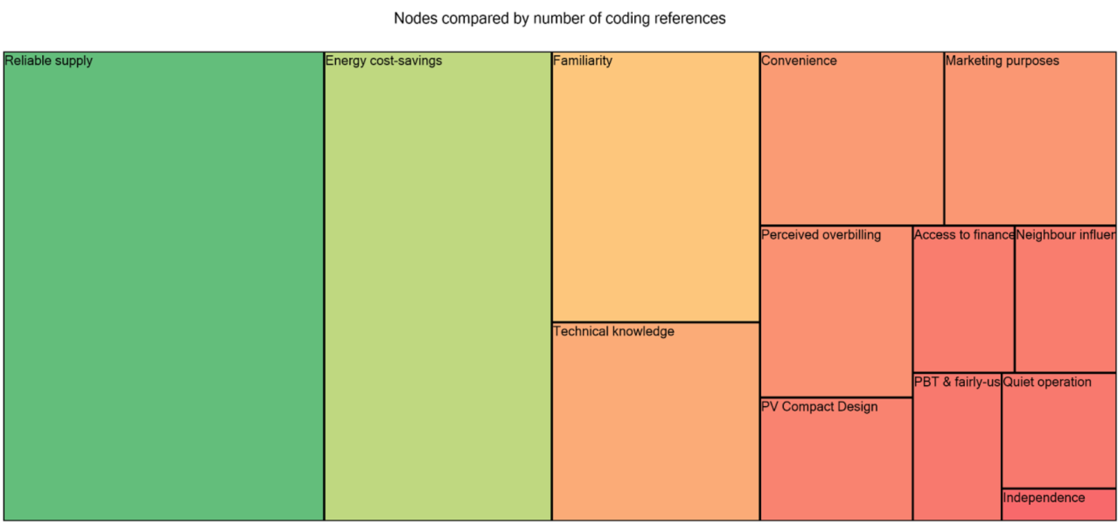

Figure 6.10 Tree Map of the motives for PV adoption with regard to coding references.

All the adopters interviewed found PV to be very reliable and better than current grid electricity as well as power supplied using petrol and diesel-operated generators. The rise in PV utilisation in Nigeria could be seen as a form of silent protest by households who are dissatisfied with the erratic power delivery they receive through the national grid and the inability of their hydrocarbon generators to *consistently* meet their energy needs. In terms of consistency, the shortages and hoarding of petroleum products not only makes the ownership of generators almost meaningless, but also adds to the expense as petroleum marketers charge inflated rates duing scarcity. This can be worse with black market operators. Thus, the innovative adopters described PV as the most rational source of power supply given the national power situation.

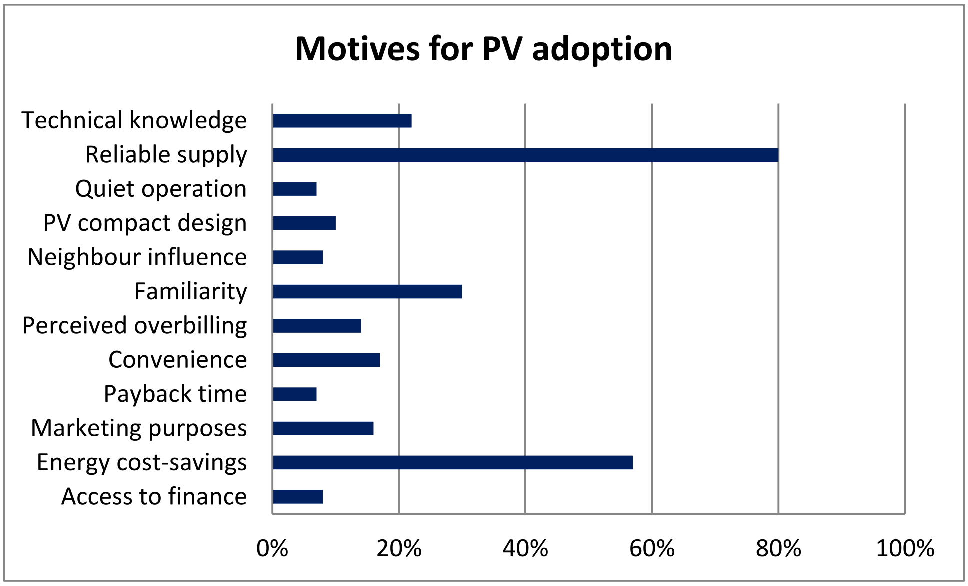

Figure 6.11 Motives for PV adoption

Other words and phrases used to describe PV included: it is more advantageous, it is rugged, regular, uninterruptible, efficient and dependable. Solar PV was not only a reliable power source as regards guaranteeing constant supply but PV electricity was also seen as more stable than grid and conventional generators. To elaborate on this point, adopters made comments in relation to power surges from grid electricity provision which affected their appliances, especially LED lightbulbs, but said that this problem was non-existent while using solar panels. The existence of power surges points to the poor quality of grid electricity sometimes received by end-users.

Overall, the opinions on PV generated electricity was positive. What was even more remarkable was that adopters whose systems eventually failed held this same optimistic view. Two of the adopters had systems that lasted for 3 and 6 months respectively as can be seen from the pie-chart representation in Figure 6.12. This short lifespan did not create a dislike for or disapproval of PV as would be expected. The adopters instead believed that the issues arose from not having had sufficient funds to pay for a fully functional system. They also attributed the quick PV breakdown to having installed an undersized inverter commensurate to the panels' capacity.

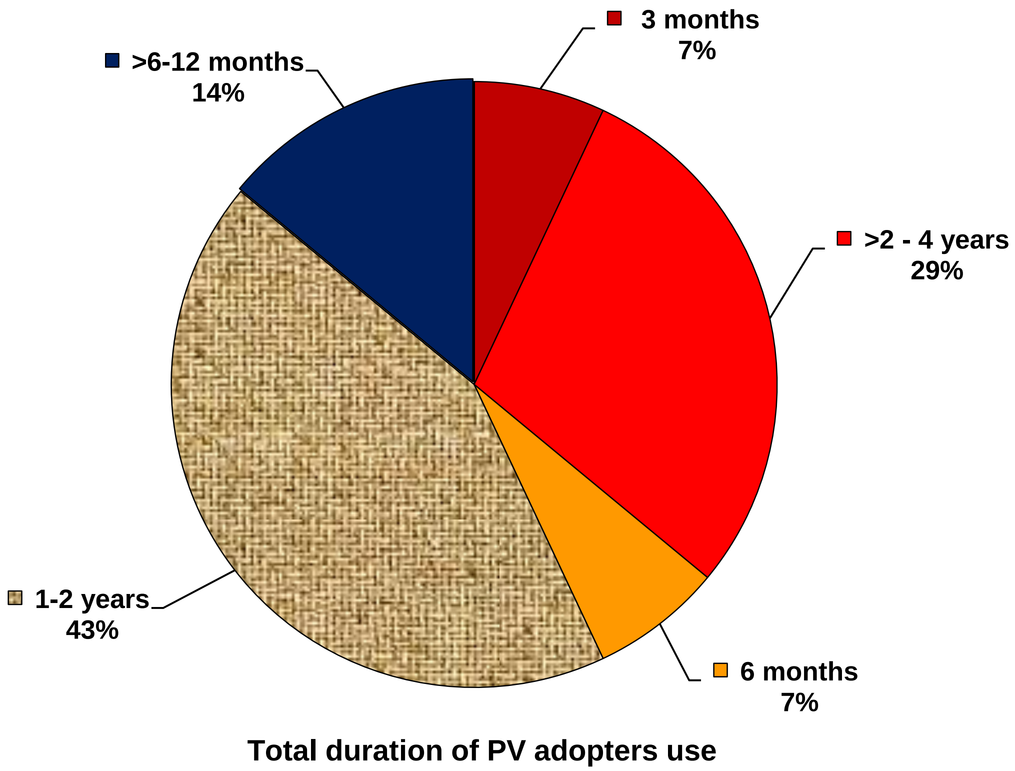

Figure 6.12 Total duration of PV use by the households

For example, regarding the breakdown and subsequent abandon of his PV, the adopter who used his PV for a duration of 6 months said:

> "I don't think it is the problem of the solar panels… It's the case of me not buying a proper inverter for the panels. You know, without good inverters, you can't use solar panels well. They were four batteries, but the inverter that came with mine was too small and inadequate for my panels… But I am very sure that the panel works for years."
>
> - *B. R.*

Regarding this same problem, the adopter whose system lasted for 3 months stated:

> "As it is now, it is faulty… It's the battery. But, I still want to use it. It's just that I'm waiting for my friend to come and fix it."
>
> - *D. B.*

The pie chart demonstrates that most (72%) of the adopters had their system working efficiently for a much longer period of time. 43% had their systems for between 1 to 2 years while about 29% stated they have had theirs for a period of 4 years without any problems. Fewer users had use of their PV for a much shorter time (under 6 months) when it failed.

The difficulty of comprehending the above two adopter's optimism, despite having experienced failed systems within 6 months of installation, is mollified when the issue of blackouts and prolonged outages faced pre-PV on a daily basis are taken into account. The security and feeling of constant power that PV guaranteed daily for even 3 months would be something people living in areas prone to regular power outages would find appealing and want to continue. Thus, it becomes easier to see why PV could have such an effect.

A loss of energy security arises when conventional power supplies no longer seem predictable. From the findings, PV is evidently a solution to the power supply insecurity problems faced by the households and seen as a form of protection against the daily annoyance of power cuts.

- **Energy cost-savings**

Aside power outages; the second most important driver of PV uptake in Nigeria was found to be energy cost-reduction. Figure 6.9 above provide clear evidence that energy cost-savings represented almost 60% of the reasons behind consumer uptake of PV in Lagos, Nigeria.

This finding was surprising because of the widely acknowledged high initial cost of PV modules. Most of the adopters clearly thought that in the long-run, PV power was more economical than the use of generators and grid electricity, with some specifically given a calculation of the cost-savings. Many remarks were made in relation to the savings derivable from PV use.

However, they all agreed that the initial investment cost was a huge barrier for many to uptake despite the long-term economic benefits of PV. The strong perspectives held that PV was much more cost-effective than grid power and generators can be seen from remarks such as this:

> "PV is unquestionably cheaper and it makes '*light'* always available for me. Solar panel is cheap… It's like you are wasting money when you are using generators."
>
> - *D. B.*

When asked why he chose PV when a generator would have provided a similar level of service, another adopter added:

> "Well, generator is out of it! It is too expensive to run… When you consider the whole estimates, PV is still cheaper than grid supply though the initial cost is a bit expensive but at the long run, PV is cheaper than grid electricity supply and generator use."
>
> *- B. C.*

The views on PV as cheaper were not limited to its comparison with the cost of purchasing fuel or paying for grid electricity bills. Adopters also compared the benefits from the vantage point of maintenance costs. Most adopters were of the opinion that PV utilisation entailed lower running costs than conventional generators.

In consequence, concerned households and other individuals have been seeking out better alternatives in the form of PV and inverters. The adopters concluded that conventional electricity sources were now uneconomical and a waste of funds. Cost-savings together with levels of power supply received by households are the biggest PV adoption motivators.

This is also evidenced by the decision of some PV adopters resorting to its use only in their homes while some others employed the use of PV solely for business. The reasons behind these single-use actions were questioned and the most responses ranged from power outage levels to cost implications. For instance, one business adopter responded to the question by saying that:

> "Where I live the electricity supply there is okay at least and lasts for up to 6 hours per day. I considered that it is more feasible to use inverter-only there as the grid supply for that 6 hours will charge my batteries to last me for the rest of the day. In my office area, the grid supply is not as good. That is why we use solar panels here."
>
> *- S. B.*

However, almost half of the adopters used PV for the provision of power both in their homes and for business purposes as exemplified below by Figures 6.13 and 6.14 respectively.

Figure 6.13 Residential PV installation in Lagos, Nigeria

Figure 6.14 Commercial PV installation in Abuja, Nigeria

- **Familiarity**

PV adoption motives were not limited to technical and economic factors. The third most significant reason driving PV uptake in Nigeria was found to be familiarity with PV energy systems. This position represented about 30% of views. Many adopters often made statements relating to being familiar with PV. Some of the comments made cited the number of years they have been aware of it. Few others said that they deliberately made certain electrical connections in their dwellings to accommodate such modern energy systems like PV. Others said they have known about inverter systems as a reliable back-up for over 10 years.

> "I already knew about these things a long time ago… Members of my household understand these things... We are aware of connections we can or cannot make… We have particular appliances which we connected to the inverter… I

try to adjust what I am using in order to conserve more power to use at night. I usually exclude things like air-conditioners from the inverter system because the starting power of air-conditioners and deep freezers can be very high."

- D. F. and F. I.

Another adopter gave a more detailed account of how his knowledge helped him identify and overcome problems with his installation:

"Awareness is very important. I expected my brand new batteries to last at least 8 hours for me. I knew that from the problems I was experiencing with my system, my batteries were not good enough. I kept telling my installer that they were not good and should be replaced and my installer was forced to change them. If I didn't know, I would have thought that that is what I am supposed to get from the system."

- F. I.

Because of the awareness of PV technology by many of the adopters, their expectation and confidence that PV will deliver as long as it was used correctly was clearly visible. Adopters' perspectives on familiarity also assuage the views sometimes put forward on PV complexity, as most said they felt very comfortable using it. This familiarity with PV systems created a kind of assurance for these adopters despite its limitations.

As illustrated in the diagram in Figure 6.15, PV reliability, energy cost-savings and familiarity were the three most ranked drivers of PV uptake across tenant groups. This means that these views were relatively the same between home owners and those who were renting their properties.

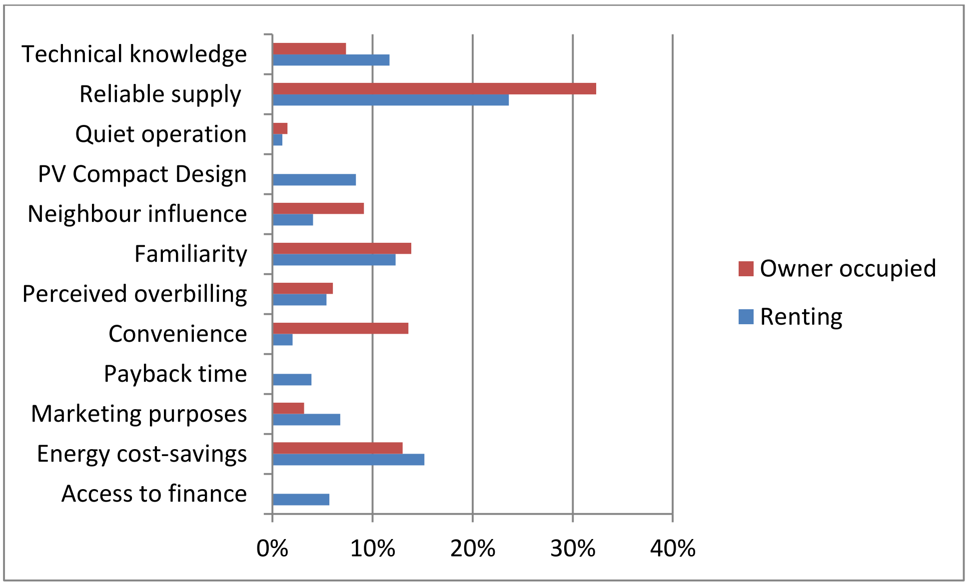

Figure 6.15 Adoption motives by tenant groups across categories

- **Technical knowledge of PV**

Closely related to familiarity was the observation that adopters had a very good technical knowledge of energy systems in general. Technical knowledge as a motive represents 22% of the references. One possible reason for this would be the number (six) of electrical engineers and PV power system dealers interviewed. As a result, it was thought necessary to separate familiarity from technical knowledge.

The terms and language this group of adopters employed to explain their position and the reasons for using PV pointed to a very high degree of expertise in electrical energy systems. Most of the points expressed by this group could not easily be made by a novice and required higher level of knowledge than mere familiarity. It was this knowledge that enabled this group of adopters to discern that, based on their low to medium energy demand, PV was the best option. These adopters also paid particular attention to the appliances they utilised and many admitted purchasing energy-saving appliances as much as they could.

Therefore, all the adopters who had high technical knowledge of PV energy systems were familiar with PV but not all those who said they were familiar with PV had high technical knowledge of it as earlier shown in Figure 6.11. However, collectively, familiarity and technical knowledge contributed about 52% of PV adoption decision. Familiarity and technical knowledge can help potential adopters distinguish between the different qualities and efficiencies of PV modules and have appropriate expectations from their installations.

- **Convenience**

There were other relevant social factors driving PV uptake. The need to minimise inconvenience was frequently alluded to and represented about 17% of the reason behind uptake. It was often referred to in relation to the recurring disruption from the national power supply and its effect on the wellbeing of the households. Associated inconvenience from using generators was also highlighted as a motive for uptake. Searching for where to buy fuel products, regular visits to filling stations, the breakdown of the generators and the regular need for generator repairs were cited as critical drivers.

Some of the shared views include:

“The inconvenience of going to switch on and switch off servers is stressful so cost is not the issue really.”

- D.F.

Another added:

“PV makes sense. For instance, I don’t have to be buying fuel for generator use all the time. That’s the concern. There is the comfort aspect too as I don’t have to worry if there won’t be *light*[25] to charge my phone, to iron my clothes and other things you know. Mentally, I’m much more stable as I’m no longer worrying about whether there will be *light* or not.”

- D. S.

A third adopter remarked:

“I find solar panels very convenient. Using generators can be so problematic. Apart from the noise which is a nuisance, there is constant purchase of fuel, you need to service the generators and you need to buy oil. The generator will go bad, you need to fix it. I am familiar with solar panels and find it very comfortable to use. The switch over system of my solar inverter means that both power from PHCN and the solar panel are channelled into the inverter. The switch-over is a seamless connection.”

- F. I.

From the above citations, there is an apparent overlap in some of the factors driving uptake. This is due to the interrelationship between the themes. For example, adopters referred to their familiarity with PV, while making mention of its convenience as well as linking it with disturbances from generator noise. The desire for convenience is driven by a quest for a more regular supply which PV seemed to provide.

- **PV Design and Quiet Operation**

The preference for PV against other forms of existing power supply also had to do with its smart design. Its relatively simple structure means that there are no moving parts in comparison with petrol or diesel generators. PV can be easily installed with the only space requirement being the building roof where it is often mounted. In contrast, an internal combustion engine like petrol generating plants take up ground space and can

[25] Many Nigerian households casually refer to electrical power as ‘light’.

leave stains on the floor or place where it is positioned, due to petroleum and oil lubricant spills and leakages.

A notable point made in the interview regarding PV design was that its installation turned out to be a ***mechanical solution*** to the problem of generator use fuel fraud. An adopter who ran several business shops narrated how his PV installation helped him curb being defrauded by his employees.
He said:

> "I tell you something. In my shops when I am away, I have been having this issue where my staff members do not buy fuel for generator use but tell me that they did buy fuel. There might have been central electricity supply and they will say oh there was no *light*; that they bought fuel when they didn't buy fuel. So I have used my PV installation to cut them off. It is actually saving me a lot of money. They can tell you that they bought fuel and they used generator from morning to night when they didn't use it."
>
> \- *F. I.*

This particular scenario described above was made possible because the PV household made use of a switchover connection allowing PV to switch automatically to grid electricity when central power was restored and vice versa. Therefore, depending on how the connection is made, PV can help safeguard customers from such fraudulent behaviour by employees or family members.

Other key assertions made on the design of PV were made in relation to its durability and can be seen from comments such as,

> "It's only the inverter and the battery that is the physical component there. If there is a need for replacement of certain parts, we normally look to the battery."
>
> \- *B. C.*

The structure of a PV system would also imply that it can be mounted anywhere that meets the requirement in terms of solar radiation and building orientation. One of the adopters installed PV because he was living in a more rural side of his city where grid connection was lacking. Given his location and the difficulty of reaching the city area to purchase petroleum products, this adopter considered PV to be the best offering. This decision was made easier by the structure of a PV device which allowed for easy transportation. The compact design of PV technologies also makes for its rigidity and stability.

Regarding PV's solid design, one adopter said:

> "The solar panel is not what we normally replace often because of the longer period of manufacturer guarantee."

Standalone PV panels also have the advantage of power balance, unlike grid-tied or base grid electricity which can suffer sudden fluctuations. One adopter highlighted this problem by stating how it can be difficult to use LED lightbulbs with mains electricity in grid-unstable regions because of the intermittent power fluctuations experienced. These imbalances affect inverter performance and lead to shortened lifespan of the lightbulbs. According to the adopter, these surges and fluctuations do not affect PV and LED bulbs making them a better choice overall.

> "Off grid solar panel system is better than inverter-only systems because the issue of power surges that come when you charge with grid supply and generator is avoided. The use of inverter requires a steady current which only the sun can provide."
>
> - *F. F.*

Also related to the need for convenience and PV design was the adopting householders' mention of generator noise as a problem. As a function of its design, PV operates noiselessly. Therefore, it readily appeals to households who desire a quiet and peaceful abode. These views expressly indicate that all the renewable generators found PV technology to be very ideal and compatible with their lifestyles. Concerns about generator noise were the only direct mention of environmental pollution in the interviews.

Nevertheless, when the adopting households were stating their opinions on ways by which uptake can be encouraged, one adopter added that adopters should be recognised for not polluting the environment. Together, factors related to PV design and quiet operation represented about 17% of the drivers of PV uptake.

- **Marketing purposes and access to finance**

PV further proved to be a self-promotion device due to its high visibility. An important factor impacting PV adoption which was cited was its use for business promotion. This was primarily done by the dealers and installers who even went as far as granting hire-purchase forms of financing, providing discounts and giving one-year warranties for systems sold. This use of PV as a marketing tool by PV dealers and installers was found to be an important source of advertising and information dissemination. The low level of awareness was seen as a hindrance needed to be overcome.

PV visibility helped to create more awareness and increase sales. Hence, using PV on the roofs of their shops was in a way the business promoter for this group of adopters. 16% of the motivation for PV uptake was for publicity and marketing purposes as shown earlier in Figure 6.11. But, the cumulative reference made towards PV usage for promotion, including the provision of financial support, was 24%. The image in Figure 6.16 serves to illustrate such business usage of PV in Nigeria. The property served as a residence and for commercial purposes.

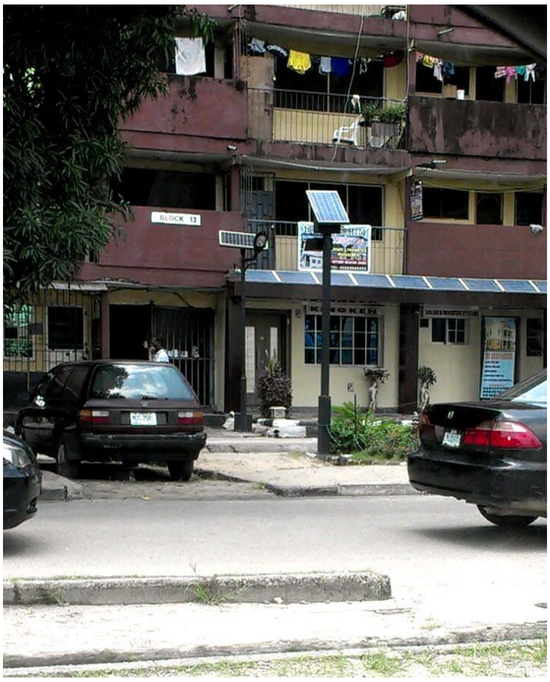

Figure 6.16 PV installation in a business premise in Anthony Village, Lagos.

Relevant statements made included:

> “We installed PV as a marketing strategy because we are involved in the solar equipment sales and installation business. When our customers come then see that we use it and it works.”
>
> *- S. I.*

Another adopter emphasized the situation by linking it to low level of awareness thus:

> “Knowledge is a key problem because people do not believe it works. They must see that it works before they will accept the technology. That was why we installed it to convince people that it works. When they see you using it, they realise it is not just that you want to make a sale, that it actually works.”
>
> *- F. F.*

In relation to providing product warranties one installer said:

> “Like now, we have our own inverters. We manufacture inverters and we give one year guarantee. If there is any failure, we fix it free of charge.” Another added, “We do give warranty for PV and module components purchased from us.”
>
> *- B. C. and F.F.*

Pointing to certain demands by some customers to install the purchased PV system the way they chose, an adopting installer said:

> You know, some people want to install it their own way. If you want to install it your own way, we do not give guarantee.”
>
> *- F. F.*

Finance provided by some dealers also enabled some adopters to install PV. Because of the risk of financial loss involved, this form of finance was based on friendship and trust. As can be seen from statements such as:

> “I give to some people that I know hire-purchase kind of support. The initial payment is part payment, and then we spread the remaining balance bit by bit.”
>
> *- F. F.*
>
> “You know, not many people can afford a big PV system. I actually personally fund most installations for individuals as it is a way of encouraging them and making them gain confidence in PV.”
>
> *- S. B.*

One adopter who benefited from such support was quick to point to this source of motivation and said such acts would serve to encourage people to install PV in their premises.

> “The major problem most people have is the price. I was very fortunate that I got my solar panels from a neighbour who is a distributor and I was paying him by instalments. If people can get the kind of support I got, they will start to key in. When people can acquire it and just pay gradually, even from the savings they make from not using fuel, it becomes very easy for them to acquire it.”
>
> *- F. I.*

Increasing awareness and consumer perception of PV and availability of finance would be crucial in any promotion agenda in this nascent industry.

- **Perceived overbilling**

Closely related to energy cost reduction, but a viewpoint which will be highly relevant in energy efficiency drive and PV innovation diffusion in Nigeria was the perception by some adopters that their energy bills were distorted. There were remarks made that pointed to a distrust of the national electricity provider with perceived overbilling taking approximately 14% of factors influencing PV uptake. Many of the PV adopters shared the belief that central energy metering and bills were inaccurate.

The adopters notion that bills received differed greatly from what was consumed resulted to responses such as,

> “Our grid supply here is not properly organised. We often receive estimated bills of what we did not use. The bill I was getting was for someone living in a four bedroom apartment multiplied by three. I don’t need that kind of outrageous amount.”
>
> *- B.C.*

Another installer stated:

> “The bills people receive are not reflective of their use.”
>
> *- D. T.*

This position was held by both the PV dealers and the general adopters. These negative views and doubts about electricity tariffs particularly revealed this was a reason why some households are not too concerned about energy use efficiency. For example, when the question regarding whether adopters were utilising low energy devices was asked, the adopter whose system lasted for 3 months answered yes, then added:

> "But, since mine malfunctioned, I have replaced the energy-saving bulbs with filament bulbs."
>
> *- D. B.*

This statement was unexpected but very revealing. Besides, the adopter did not elaborate on this remark as he continued explaining that he was waiting for his friend to come and fix his failed system. The remark meant that energy curtailment and management was limited to the use of solar panels but not with grid or generator-supplied electricity.

Another adopter remarked:

> "I only had few LED bulbs in the house because there was no need for such actually. Honestly, you do not worry so much about energy saving appliances if you rely on grid supply because it does not matter."
>
> *- D. T.*

Some others had a rather gloomy outlook of the situation and future prospects of the central power sector in Nigeria.

> "People have no choice now because power will not be good for a long time in Nigeria."
>
> *- D. F.*

- **Influence of neighbour PV users**

Being friends or neighbours with a PV household was found to impact uptake. Herein lies the power of Word-of-Mouth (WOM) and opinion leadership towards PV adoption and diffusion. Some of the respondents reported knowing someone using it or who inspired their investment.

Some of the relevant statements made in this regard include:

> "It was a friend who installed it for me. There was an agreement that we had so I am supposed to be paying the person by instalments."
>
> *- D. B.*
>
> "My solar panels, I got them from a neighbour who is a dealer of PV systems."
>
> *- F. I.*

When asked if they would recommend PV to other households as a reliable power source, all the adopters answered yes but the adopter who used his installation in his hotel went further to detail the number of people he had already referred.

He responded:

> "In fact, I have introduced three of my friends to the technician who installed my own."
>
> *- S. A.*

- **Shorter Payback Time (PBT)**

On another application level, PV adoption was as an indirect result of shorter payback time (PBT). This cost-related factor was responsible for about 7% of the reasons for adoption. The individual said that aside the fact that PV was cost-effective, the time taken to recoup investment was short. In his case, the PBT was given as 15 months.

This adopter said:

> "The high cost of a solar system is a one-time investment and the thing is that you can recover your money. Sometimes, within 1 year you can recover it."
>
> *- F. I.*

When probed further, they mentioned that they made use of second-hand panels and batteries. With the exception of this adopter, comments on PBT were exclusively highlighted with reference to the use of second-hand PV devices and the contributions were from two people. A subsequent question on PBT specifically asked how long they thought it would take to recover the cost of paying for their system. To this, a majority answered in a straightforward manner but some adopters did not hide their surprise at the question on PBT. Examples of some responses include:

> "You see when you are talking about cost, it is not actually cost. The inconvenience of going to switch on and switch off servers is stressful so cost is not the issue really. I don't have UPS at all because there is no need for such. Honestly, I never thought about payback time, convenience is more important to me."
>
> *- D. F.*

After dismissing PBT as irrelevant, another adopter gave an immediate cost analogy of PV and generator use thus:

> "The payback time is not relevant to me because if I am buying petrol or diesel to run my generators, I will spend more than £12 per day. If you calculate that for a year that is over £4000; whereas; on the PV system, I spent about £4400 and I only need to change the batteries after about eight years. In a year and one month, I will recover my money."
>
> *- S. A.*

The most phenomenal reaction regarding PBT was from J. A. who surprisingly was an electrical engineer. When asked about payback time, there was clear astonishment first, then a long silence:

> "Wow... If we consider the times that there may be electricity, let's say in three years but no more than that."
>
> *- J. A.*

In general, the payback time (PBT) quoted ranged from 1 to 5 years but PBT or return on investment (ROI) did not seem to matter for a majority of the adopters. Of course this would be different for other type of investors who may enter the PV market primarily to profit.

6.5 PV usage and energy efficiency

In order to ascertain whether PV could help bring about household energy use efficiency, its contribution towards helping to modify household energy consumption behaviour was examined. Through the inclusion of questions bordering around whether the adopters installation had a monitoring meter attached, the location of the device and how frequently the monitor was viewed, this important aspect was analysed. The findings were positive and revealed that PV use can contribute to increased energy use awareness and in consequence encourage de-consumption.

The key reason behind the energy use management uncovered was the presence of a feedback meter on the inverter. All but one of the adopters stated having a display monitor on their PV inverter. With most of the adopters' inverter located inside the dwelling, there were more regular checks by the concerned households. Figures 6.20 and 6.21 represent this finding.

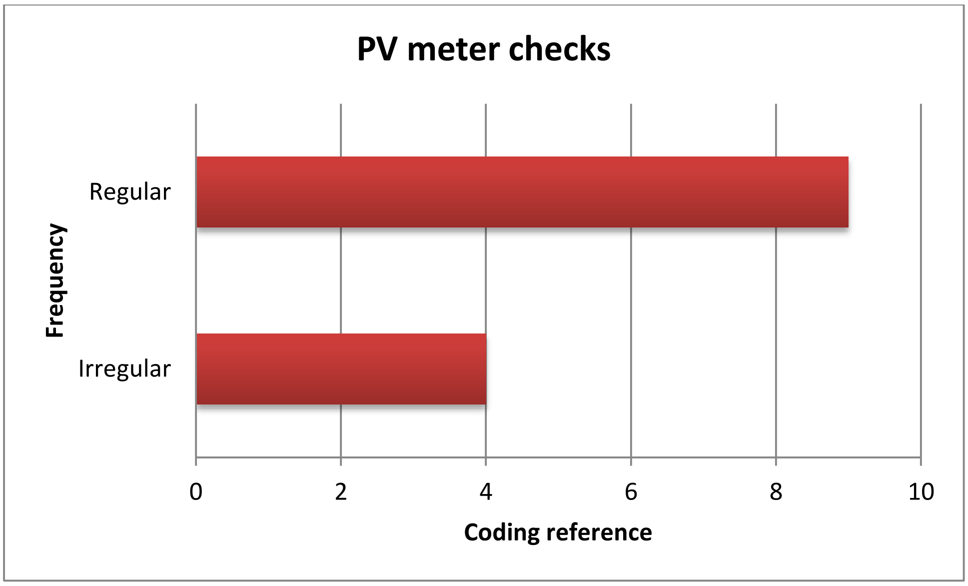

Figure 6.17 The effect of PV meter on energy management

The presence of an inverter monitor can influence the number of checks on a PV system which can in turn lead to more energy use conservation.

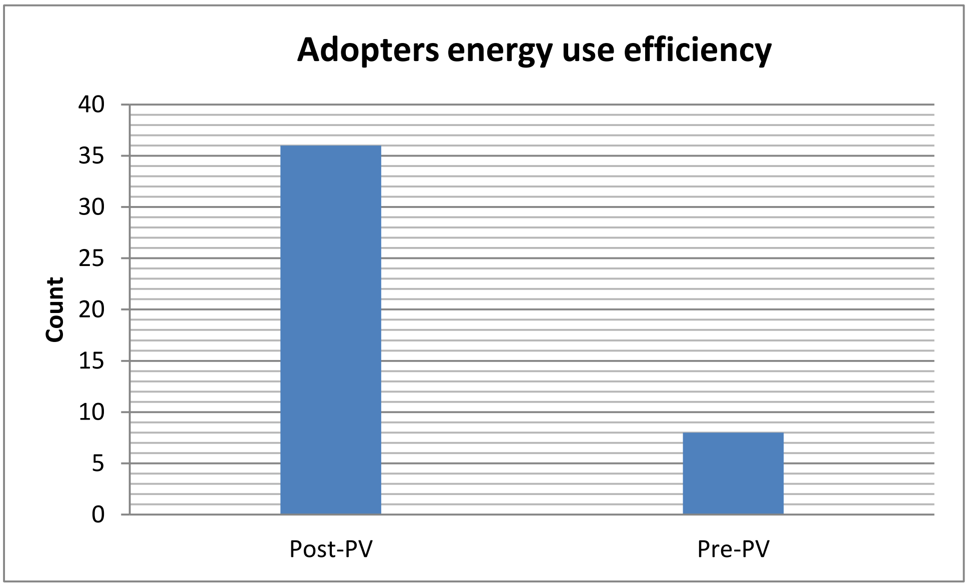

Figure 6.18 Pre and Post-PV energy use efficiency of the adopters.

As the chart in Figure 6.21 above indicates, there was an almost five-fold increase in energy use monitoring and conservation following the introduction of PV. The use of PV directly impacts on household energy demand and fosters interaction between the users and the system. This interaction is the direct result of PV output limitations.

6.5.1 Problems faced by the early adopters and stated barriers to PV uptake

To help confirm the questionnaire results the innovative adopters' views on hindrances to uptake and other problems encountered in the course of using PV were sought. The most significant barrier to PV adoption were found to be high capital costs, dishonest installers, low level of awareness, absence of government incentives and weak regulation**.** Of all the hindrances mentioned, high initial cost of installation was the most cited.

- **High investment costs and lack of finance**

The investment cost of a PV system and lack of finance are the biggest impediments to uptake as confirmed from the interviews. While many find the technology appealing and see its benefits, the high initial cost prevents households from adopting PV. As shown in Figure 6.22, high investment costs received the most response in relation to adoption barriers and represents about 60% of the references made by the adopting households. When combined, high investment cost and lack of finance accounts for 81% of the barriers to adoption.

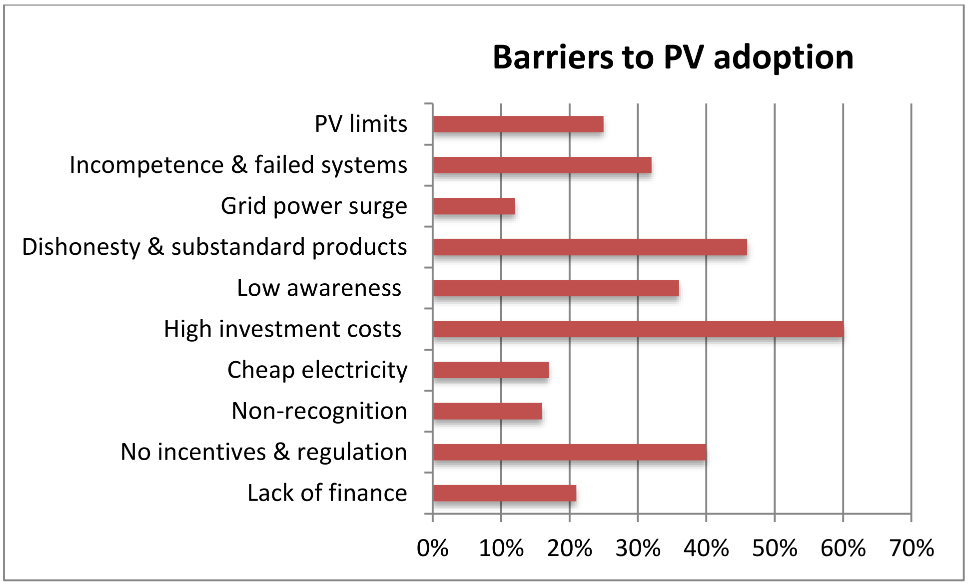

Figure 6.19 Barriers to PV adoption

Some of the comments made include:

> "Purchasing power is still a key problem. Not many people can afford it due to the high upfront cost. Most people tend to withdraw, because of the high cost."
>
> *- B. C.*

> “The major constraint to uptake for most people is the bulk money involved.”
>
> - *F. F.*

> “It is the upfront cost that is a problem. The benefit is not something a user will realise immediately. If not for the price, I know every roof in Nigeria will be solar panelled.”
>
> - *S. B.*

High capital cost would mean that not many households in Nigeria can easily pay for a sizable PV. Although there seemed to be an interest in this modern renewable power technology, this interest does not readily culminate in uptake as a result of this barrier. When it did, the outcome was that individuals ended up installing under-sized systems incompatible with their energy demand, leading subsequently to system failures as described here:

> “It would have turned out to be a good investment if I had money to pay for a suitably-sized system.”
>
> - *B. R.*

> “The cost of acquiring it is the problem. So people prefer to continue using what they have and be spending maybe like £8-£12 every day instead of putting in about £3000 or thereabout for good-sized panels.”
>
> - *F. I.*

This issue of high capital cost and lack of finance is further compounded by the need to utilise energy efficient appliances which are generally more expensive than their conventional equivalent. PV efficiency limits also means that households who opt for it would have to incur further expense in the form of purchasing low energy appliances. Thus, when potential adopters weigh the whole cost estimates, some decide to continue using gasoline engines.

Describing how not having sufficient funds and the lack of PV knowledge led them to purchase 8 batteries rather than the 16 batteries recommended by his installer, another adopter said:

> “You know, when I installed my PV, I wasn’t having much money and I was doubtful of the technology so I didn’t want to invest too much money on something I was not sure of.”
>
> - *S. A.*

Another user who felt that PV made him a lot more conscious of his energy use, said that so many changes that he would have wanted to make, was not possible because of the high prices of low-carbon household appliances.

> "I would have changed my refrigerators to energy-saving ones but the cost is too much.”
>
> *- F. I.*

High capital costs also made potential customers doubtful of PV power and experience cognitive dissonance as some responses showed:

> “People are also sceptical of the components and the system as a whole when they consider the amount involved.”
>
> *- B. C.*

> “Some people complained that the price was too high and started backing out from the project. They want 12 volt battery with any inverter at all, just for them to have power for few minutes they are okay with that.”
>
> *- S. B.*

- **Dishonesty, incompetence and substandard products**

PV adoption and diffusion in Nigeria has also been hampered by the dishonest practices of some technicians. Generally emphasized by both those involved in the installation business and households alike, dishonest installers and their use of poor quality products was responsible for 46% of the responses on adoption barriers. Closely related to it was incompetence at 32% which they said contributed to the number of failed projects in the country. This type of problem can be exist in a largely unregulated market like has been the case in Nigeria.

Relevant remarks include:

> “There was a time I had problem with my panels and I was asked to change the batteries. I did but the new ones that I got were not actually new. The batteries were actually 150 watts; they now changed the labels to 200 watts. You know these guys that install the systems; they play a lot of tricks. That is why some people tell you that solar panels don’t work.”
>
> *- F. I.*

This statement was confirmed by those in the trade as a huge problem faced by the industry:

> "A key problem we usually have is that, you know in Nigeria, they bring in sub-standard products. That's why sometimes; you find that a battery that was okay at the start, after six months, the battery will not be able to back up the user again."
>
> *- D. T.*

In support of this view, another dealer added:

> "The problem I had initially was when I bought the panels, some components were stolen and we never knew. When I check the solar inverter it will be showing the level of energy in the battery as high but the battery will not be charged. So after some checks, we now found out that it was a missing kit that was the source of the problem."
>
> *- S. B.*

Another particularly highlighted problem of the Nigerian PV industry was the low technical skill base as detailed here:

> "I once had a problem with my charge controller. The person that I called in to help me fix it, I didn't know that he didn't have the required knowledge. He did work on it but it was still not working effectively so I later got someone else."
>
> *- F. I.*

When another installer was asked if he had had any case of a system failing, he answered yes and went on to explain why it happened thus:

> "One that we observed that failed was a streetlight installation. Somebody else designed it and we installed it. I was later asked to go and inspect the project and found that it was not a component problem but a design problem."
>
> *- B. C.*

> "People who are trying to show interest are not really encouraged because of the actions of those who do not have experience. The sole aim of some installers is to make profit; and not to meet the customers' needs. And that has really given the technology a bad publicity."
>
> *- D. T.*

The references made towards incompetence were found interesting. Some of the images of improperly installed PV systems the researcher saw during the field trip support the claims. Examples of this can be seen from Figure 6.23 where a system was installed under a tree which shaded it from the requisite daylight necessary for its proper function. In Figure 6.24 there are noticeable gaps in between the modules in the way they were mounted meaning the panels were not properly matched. Such defects can arise where there are no regulation and where unqualified persons engage in installations.

Figure 6.20 A shaded streetlight installation in Ikeja, Lagos

Figure 6.21 Poorly matched and mounted PV modules in Lagos and Abuja

Some of the defective or failed systems were linked to the adopting households' violation of the recommended operational procedures. This happens when a system is used and not maintained in a way that is consistent with its original operating requirements.

- **Absence of Government financial incentives and regulation**

The third most cited barrier to uptake was the lack of Government support in the form of incentives and policies to protect the emerging industry**.** The absence of this sort of support received 40% of the responses. For many, it was a key reason why the industry seemed to be struggling to take off. Most of the major problems that the adopters reported are in one way or another connected to competition in an unregulated market. Since PV uptake has been largely market-oriented in Nigeria, the role of governance towards legislation and consumer protection becomes increasingly more important.

Key comments with respect to the above points include:

> "If Government can help to regulate the market, it will bring about a reduction in the number of poor quality systems we see in the market today which has affected consumer confidence in PV."
>
> *- D. T.*

> “If Government can subsidise PV and make it readily accessible and cheaper for consumers, it will encourage uptake. We import all our systems. Government should create an environment where there will be an outlet for manufacture of PV systems and components.”
>
> *- S. I.*

Making reference to the PV promotion approach in use in some advanced countries another added:

> “The thing is that Government subsidize the use of solar panels abroad and people generate power and sell to the national grid. Consumers supply excess to the national grid and buy from the grid when they generate insufficient quantities. If I have the opportunity to sell my surplus energy back to the grid, I will participate.”
>
> *- F. I.*

As shown earlier, some of the adopters shared how without the financing they received, it would have been difficult for them to obtain a PV device. While other adopters’ criticised Government inaction on people who through their bad practices bring the industry into disrepute.

> “Government has also been too lenient. Even most street-light projects the Government contracted out, after three months, the system dies off. When such happens, it becomes difficult to convince people again.”
>
> *- S. B.*

Although related to the lack of Government incentives, particular mention was made with reference to dearth of a recognition and appreciation for PV users. Non-recognition accounted for 16% of the responses on obstacles to uptake and in combination with the absence of incentives represents 56% of consumer concerns. This group of adopters were very aware of their contribution towards emissions reduction and environmental sustainability.

> “If government can encourage people by maybe letting them pay less tax or paying them for not polluting the environment. Since I am using PV systems, if there is any way I can benefit from doing this, it would serve to encourage people. We need something to make people see that their uptake of alternative energy sources are recognised and rewarded.”
>
> *- F. I.*

- **Low awareness and cheap electricity**

Low level of awareness was the fourth most significant barrier identified. 36% of the adopting households' had low levels of awareness. Unfamiliarity and lack of PV knowledge and energy supply in general was seen to impact uptake. In addition, decades of subsidised electricity tariffs was believed to have created the notion of cheap electricity, which accounted for 17% of the barriers.

Among the contributions on this perspective include statements such as:

> "People in this part of the world are not used to that type of energy supply. They see energy as cheap. Most people when they are leaving their homes they don't turn off their appliances so when they now consider using solar panel, they may run out of power because they are not used to conserving energy. Their high energy consumption makes it look as if they don't have control over it."
>
> *- B. C.*

> "Some of my employees do not know the difference between grid-supplied electricity and solar power. They want to use every appliance in the shop."
>
> *- F. I.*

> "Initially, we were having problem of staff members putting on too many appliances. Many Nigerians do not understand renewable energy due to the level of education."
>
> *- S. B.*

> "The technicians play on the ignorance of consumers and give them sub-standard products."
>
> *- F. I.*

Aside doubting the efficacy of PV to deliver the required power needs by some, and the knowledge and awareness concerns, other observations pointed towards the maintenance culture of some adopters. Disparate views were given regarding maintenance. There were those that ensured routine (every 3 months) maintenance of their systems to ensure it was in perfect working order. However, a number of the adopters mentioned not cleaning their modules. Others said they relied on rainfall. While some stated categorically that PV does not require cleaning.

Some of those who did said:

> "You know, our country is too dusty, Nigeria is too dusty. Normally we clean up the panels because a lot of dust settles on the panels so they receive a better

reflection to absorb the necessary energy required. Some technicians also create problems. They do not understand or explain to clients how the system works. All they do is go and install systems without giving clients instruction on the kind of appliances and light-bulbs to use."

- *S. B.*

"Once every four months we tend to clean the modules but during rainy season it is always clean so we don't bother."

- *F. I.*

The adopters who did not regularly clean their modules stated:

"We do not clean them as some people advice because we find that it is always clean especially during the rainy season."

- *D. S.*

"We do not even clean the panels because it doesn't need cleaning."

- *S. A.*

Low awareness, misinformation and poor maintenance is the reason for the many short-lived and abandoned PV streetlight projects in Lagos like the one shown in Figure 6.25. Withholding such vital information can lead to misuse and accelerated module degradation.

Figure 6.22 An abandoned streetlight installation in Lekki, Lagos

- **PV output limitations**

The inability of a PV module to provide the entire energy demands of a household was reported to impact its adoption. This was mentioned by the adopters while expressing how they monitor their usage and manage their system. However, there was no direct criticism of PV efficiency but comments made showed its effect on the adopters energy demand.

> "My system cannot power all my appliances. If I have to power all my devices, I will need to get more panels. I try to adjust what I am using in order to conserve more power to use at night."
>
> - *F. I.*

Another added:

> "I intend to increase the capacity of my installation so that I won't have to switch off some appliances any longer when using my panels."
>
> - *S. A.*

A salient point was made by the adopter whose system failed at 6 months. When asked if he would recommend PV to friends, he said only to the well off and went on to suggest ways by which PV can be made more affordable.

> "I will only recommend PV to those who have money. A situation where solar panels can be used without the need for too many batteries and inverter will be a welcome development."
>
> - *B. R.*

The issue of PV efficiency limitations becomes all the more important in a country where households are used to plugging in all their devices. PV limitations are a huge disincentive to uptake as the high costs and limitations make some interested parties object to its use.

- **Grid power surges**

Although receiving the least mention in the course of the interviews, grid power fluctuations appeared to be a problem and accounted for 12% of the references in relation to hindrances to PV uptake. This was particularly the case with households who utilise inverter-only systems whereby they have to charge the inverters with their generators and grid electricity. For the households who relied on solar panels, the problem was less reported.

The contributions to this perspective include:

> "The major issue we have in Nigeria is grid power surge**.** If we have an outlet whereby our national grid can charge and your solar panels can charge as well, it will be good. But when the national grid comes with a superior power surge, you find your inverter being damaged. Synergy and one other inverter brand are the only ones that can withstand power surges. They have automatic breaker which makes them very perfect."
>
> - *S. B.*

A comment made by an installer regarding why he preferred to use LED bulbs for his PV pointed to a reason separate from the well-known need to conserve power. The lightbulbs also last longer as well because they tend to withstand grid power surges.

> "Since installing my solar panels, I use LED bulbs because power fluctuations does not affect LED bulbs. Power surges affect incandescent bulbs."
>
> - *F. F.*

The next section presents the Logistic regression results. The analysis was done to determine the extent to which government incentives can lead to increased PV uptake and to help identify the most significant variables to help predict the adoption path.

6.6 Logistic Regression

6.6.1 Theoretical background

To further improve on the results of the significant correlations and investigate their collective predictive power, the most relevant variables were selected from the Spearman's correlation results and used in a logistic regression analysis. Logistic regression or binary logit model is a form of Generalized Linear Models (GLM) that uses algorithms of Maximum Likelihood Estimates (MLE) to predict the probability or logs odds-ratio of an outcome. The goal of the MLE procedure is to find the best combination of predictors to maximise the likelihood of obtaining observed outcome frequencies (Tabachnick and Fidell, 2007).

By going through an iterative or recursive process, logistic models seek convergence until the best fitting model (not necessarily the only model) is eventually computed and analysed using a number of statistics including the Hosmer and Lemeshow goodness-of-fit test (Oliver et al, 2011). Unlike binary probit which is another form of logistic regression, binomial logit models do not assume distributional normality and linearity in the sample (Ryan, 1997). There can be only two possible outcomes in binary logistic models (Pallant, 2011).

However, logit models can be prone to outliers especially where cases (predictors/IVs) are grouped together in a test. Outlying cases were removed and using a Tolerance statistic, variables with high multicollinearity were not placed in the same group in the analysis. High multicollinearity can bias included variables and result to non-significance (Oliver et al, 2011). The Spearman's correlation table also shows the absence of extreme values (r= > 0.70) which can impact results. Sufficient[26] statistics was used to design the logistic model for predicting the probability of households adopting PV. As a discrete choice model, logistic regression finds common application in attitudinal and consumer preference studies (Oliver et al, 2011; Hast et al, 2015). For these reasons, it was considered appropriate for this analysis.

6.6.2 Explanation of variables used in the model

The empirical results are based on the estimation of the following expanded logit specification for a household's willingness to adopt PV:

$ADOPT_{PV}$ = income (INCREC) + education (EDUCREC) + home ownership (HOMOWNER) + power supply hours (HROFSUP) + perceived cost of PV (PERCOST) + subsidy (SUBSREC)

Where 1= (Yes) means household is willing to adopt PV and 0 = if otherwise;

INCREC is a dichotomous variable recoded into 1 = Low income
2 = Medium income
3 = High income

EDUCREC is a dichotomous variable recoded into 1 = Secondary education
2 = University degree
3 = Postgraduate

[26] Statistics that contain all the key sample information necessary to estimate one or more parameters (Ryan et al, 1997)

HOMOWNER is a dichotomous variable where 1 = Household owned their home and 0 otherwise. HROFSUP is a continuous variable representing average hours of electricity supply received by household per day. PERCOST measures perception of PV cost where 1 = Expensive and 0 otherwise; and SUBSREC is a dichotomous construct assessing adoption in the presence of Government subsidies with 1=Yes and 0 otherwise.

6.6.3 Understanding the logistic regression output

The **Case Processing Summary** on the first page of the output (Appendix D) presents the summary of the number of cases included in the analysis. Of the 200 respondents, a total of 183 cases (91.5%) were used in the analysis. The **Dependent** (outcome) **Variable Encoding** is an indication of the codes assigned to the outcome variable i.e. adopt PV. Where 1 =Yes and 0 = No. The **Categorical Variable Codings** give an indication of the categories of income and education and their respective frequencies.

Block 0: Beginning Block show the results of the analysis without any of the independent (predictor) variables used in the model. The Block 0 later will later serve as a baseline for comparing the constant model with the predictor variables included. The classification table presents the overall percentage of the correctly classified cases (62.3%). This means that SPSS guessed that all cases would be willing to adopt PV based on the higher percentage of people that answered yes to the question. The next step is to determine whether the inclusion of the predictor variables can improve SPSS' guess (correctly classified cases, i.e. 62.3%). Also under the **Variables in the Equation** section in Block 0 SPSS calculated a significance level of .001 based on the observations. An improvement in the significance level over .001 is an indication of a good model.

Block 1 is where the model actually begins as the results now include all the predictor variables. The **Omnibus Tests of Model Coefficients** gives an indication of *how well* the model performs, over and above the initial results obtained at Block 0, with none of the predictors entered into the model. This is referred to as the goodness-of-fit test. For this set of results, a highly significant value which should be < .05 is desired. There are different ways to assess whether the model fits the data. First, the chi-square value was used. A significant level of the model chi-square value <.05 is an indication that models with included variables fit the data better than one without (Arkesteijn and Oerlemans, 2005). Based on this goodness-of-fit criterion, under Block 1, the results show chi-square value of 35.660, 8 degrees of freedom and a significance level of .000 which is a better result compared to SPSS Block 0 projections.

Secondly, the **Hosmer and Lemeshow** goodness-of-fit test was applied. This test further supports the model as worthwhile. Often described as a more reliable *goodness-of-fit test*, the Hosmer and Lemeshow Test is interpreted somewhat differently from the Omnibus Test. Here, a poor fit is indicated by a significance value of <.05. Thus, a good model is one that is greater than .05. The Hosmer and Lemeshow Test results in Block 1 show a chi-square value of 5.071 with a significance level of .750. This significance value is far greater than .05, and indicates support for the model.

Thirdly, the values of the **Cox and Snell *R* Square/Nagelkerke *R* Square** were used. Here the larger the *R* square measure, the better the model (Hast et al, 2015). The **Model Summary** table under Block 1 also provides information about the usefulness of the model with the predictors included. **Cox and Snell R Square** and the **Nagelkerke R Square** values give an indication of *the amount of variation* in the outcome variable explained by the model. These are referred to as Pseudo *R* Square statistics, as opposed to the true *R* square values found in multiple regression output. In Block 1, the Cox and Snell *R* square is .177 while the Nagelkerke *R* square value is .241. This indicates that 18% to 24% of the variability in the outcome is explained by this set of variables. If the *R* square value is ≥ 1 then the independent variables are perfect predictors (Arkesteijn and Oerlemans, 2005).

Furthermore, the **Contingency Table** for Hosmer and Lemeshow Test detail the observed and expected results. The difference between the observed and the expected values should be close if the prediction is to be considered meaningful. What is sought here is the value under the outcome of interest. As shown in the last row under adopt PV = Yes, the observed is 16 while the expected is 16.5. These values are very close and points to a very good predictive ability of the model.

The **Classification Table** serves to illustrate *how well the model predicts the correct category* (adopt PV/won't adopt PV) for each case. Comparison is made with the classification table shown in Block 0. As shown in the output, with the predictors included, the accuracy of the model prediction was 73.2%. This means that the model correctly classified 73.2% of the overall cases. This is sometimes referred to as the percentage accuracy in classification (PAC) (Pallant, 2011) and represents an improvement of 17.5% over the initial model. This is a very good predictive ability in logistic regression.

The **sensitivity** of the model is the percentage of the group that has the characteristic of interest (adopt PV) which has been accurately identified by the model (the true positives). The results of this analysis reveal that using logit models 84.2% of households who are willing to adopt PV were correctly classified. The **specificity** of the model is used to describe the percentage of the group without the characteristic of interest (won't adopt PV) that is correctly classified (true negatives). Here, the specificity is 55.1% (households who are not willing to adopt PV correctly predicted by the model).

The **Variables in the equation** table give information about the contribution of each of the predictor variables. It uses the Wald Test. What is desired here are values not greater than .05 (This represents the values that contribute significantly to the predictive ability of the model). There are thus 4 significant variables (hrofsup p = .000, educrec p = .007, percost p = .040 and subsrec p = .050). Therefore, the key contributors influencing whether a household will adopt PV are:

- Power outage (referred to here as hours of daily power supply received)
- Level of education
- Perception on capital cost of PV, and finally
- Presence of subsidies

The **B** values shown in the second column are similar to the **B** values obtained in multiple regression. These values are used in logit model equation to calculate the probability of a case falling into a specific category. The sign (positive or negative) indicates the direction of the association (which factors increase the likelihood of a yes and which factors decrease the likelihood). Negative B values imply that a rise in the independent variable score will result in a drop in the probability of recording a score of 1 in the dependent variable. Thus, the negative sign in hrofsup (-.228) indicate that the less hours of electricity a household receives, the more likely they are willing to adopt PV.

6.6.4 Synopsis of the logistic regression results

Direct logistic regression was applied on PV adoption as outcome using four socio-economic predictors (income, education, home ownership and hours of electricity supply), one attitudinal predictor (perception on PV module costs) and one policy-oriented predictor (presence of government subsidies). The analysis was performed using SPSS Binary Logit Function. Missing Value Analysis (MVA) was performed and variables missing significant portions of data related to the analysis were omitted. A rerun of the MVA showed no further missingness. Therefore the total number of cases included was 183 representing 91.5% of the original dataset of 200.

The six predictor variables were used to identify the unique and combined effects of the different factors necessary for households' willingness to adopt PV. The full model containing all predictors was statistically significant, χ^2 (8, N = 183) = 35.66, $p < .001$ indicating that the predictors, as a set, reliably distinguishes between households who were interested and those not interested in PV uptake. The full model was also able to explain between 18% (Cox and Snell r square) to 24% (Nagelkerke R square) of the variance in household willingness to adopt PV, with 73.2% correctly classified. This represents an increase in predictive power of 17.5% from the constant-only model in Block 0.

As shown on the variables in the equation table above, 4 of the regressor variables made a unique and statistically significant contribution to the model (education, hours of electricity supply, perception of capital cost of PV and government subsidies). The strongest predictor of PV adoption was hours of daily electricity supply received, which recorded an odds ratio of .80. This odds ratio of .80 implies that for every additional hour of power outage per day experienced by respondents, WTP for PV increases by a factor of .80 controlling for other factors in the model. In order words, the affected households were .80 times more likely to opt for a more reliable alternative supply source.

Closely related in adoption prediction power was education, which recorded an odds ratio of 22.3. This odds ratio indicated that university graduates or educated households were over 22 times more likely to adopt PV after controlling for other factors in the model. Other key contributory factors to the PV adoption decision were perception of cost and presence of subsidy both recording an odds ratio of over 2.5. For subsidies in particular, the results predicts that households who shared preference for PV support subsidies were almost 3 times more likely to adopt PV. The purpose of the logistic regression is not to over predict the adoption path. Rather, it is to show what is possible given meaningful monetary and non-fiscal incentives. It is only a matter of lucidly recognizing that PV development has to be supported if meaningful changes in the electricity sector are anticipated.

6.7 Summary of questionnaire and interview results and conclusion

The findings from the interview Nvivo analysis have verified much of the questionnaire results. The significant sociodemographic characteristics identified in the Spearman's correlation were age, income and education and home ownership. The interview analysis resulted in some important findings regarding the major barriers to residential PV adoption. High initial cost, lack of finance, product quality concerns, perception on PV efficiency and use of energy saving appliances all validate the Spearman's correlation result as key barriers. The supplementary barriers identified from the interview analysis which were not revealed in the questionnaire correlation results were:

- Unskilled and dishonest installers
- Low level of awareness and poor PV maintenance culture
- Weak regulatory environment and
- Non-recognition and reward for adopting households

Although there was no direct mention of technology affinity, the finding that familiarity and technological knowledge were highly important factors in the purchase behaviour, implies an indirect link with technology affinity. In the descriptive statistics the questionnaire results showed amongst other things a moderate-high environmental awareness in terms of climate change and global warming issues. Notwithstanding, environmental concerns did not appear important for the adopters in Nigeria[27]. When asked how they could install PV on a property they were renting, the adopting tenants simply said that there were no objections and that their landlords were actually happy about it. In addition, installation inconvenience and PBT were not significant barriers to PV adoption at the household-level as the interview showed. Also, the adopters were not asked questions regarding house move even though this appeared highly significant in the Spearman's correlation. But, based upon the finding that home ownership was not an important predictor of uptake, it is plausible to expect that the effect of house-move in the adoption decision would be minimal. The logistic regression indicated that alongside education, incentives will be required for PV promotion. The interview result also enhanced the questionnaire finding with respect to three key discoveries:

[27] This was also observed in the Spearman's correlation that tested motives to adoption.

- PV adoption is a function of its cost-effectiveness;
- PV use in Nigeria has increased due to dealer adopters promoting their business; and that
- PV can help control fraudulent generator fuel use behaviour and help owners save total cost.

At the beginning of this research, it was argued that photovoltaic power systems have huge potential in Nigeria and can help plug the gap in electricity supply sustainably. There is also the prospect of PV reversing the problem of energy overconsumption. Results appear to support this view but only given certain prevailing conditions. Findings seem to suggest that many of the Socio-cultural, Technological, Economic, Environmental and Regulatory (STEER) determinants to PV adoption identified in literature reviewed from Chapters 1-5 apply to Lagos, Nigeria. However, some of the findings are specific to the research context. PV has been widely reported to be a reliable technology. It has not been previously shown in studies that its adoption in Africa is as a result of power outages. It has further not been shown that households who installed them in urban areas, in such locations found it to be cheaper than conventional supply.

Of the socio-cultural barriers, lack of awareness is a major obstacle. Though still a problem, the perception that energy is cheap is one that is slowly fading with the increments to electricity tariffs and fuel prices. While the reliability of PV over other existing energy systems was confirmed, the technology-related hurdles include low technical skill base and dishonest dealers and installers. Despite high capital cost, in the long run, PV offers higher cost savings over grid power and auto-generation as previous studies have demonstrated (Keirstead, 2007; Sovacool, 2009). Limited funds and lack of finance was the biggest hindrance to purchase. It may be necessary to investigate further the most beneficial modes of support that can be made available, especially before private investors e.g. leasing schemes are introduced.

From an environmental standpoint, PV is low in emissions and can be used to manage land, air, water and noise pollution. Thus, voluntary adopters should be compensated for their goodwill. The technological and economic factors constitute the greatest drivers to PV adoption. The energy security (*consistent power*) which PV guaranteed householders and cost-savings remained the leading motivation. Just like motivations for uptake, hindrances to PV adoption were also multifaceted. But they share a common solution - incentive support. As the Logistic Regression results revealed, households are almost 3 times more likely to purchase PV in the presence of incentives than not. It also presents a case for more educational campaigns which was found to be a more significant factor in the model than income. As the Nigerian Government seeks out ways to combat the power problems it will be imperative to seriously ponder the opportunities PV power presents. Barriers to uptake can be slowly uprooted with adequate political/regulatory and institutional support.

Given the enduring power challenges, it will not be impractical to make certain assumptions here. Suppose that in a place like Lagos with a population of over 20 million people (Lagos State Government, 2015) that 1.2 million households install a 5kWp PV system. There will be massive difference to overall generation and use given the 7843.39kWh annual yield calculated using RETScreen. Even if we assume that 1000000 appropriately installed 5KWpeak PV systems each generate lower, say a modest 4800KWh each year then the total output in 1 year is: 1000000 * 4800 = 4800000000KWh => 4800GWh[28]. As the number of households in cities rise, the opportunities PV presents become clearer. The urban population in Nigeria was estimated as 47% compared to the world average of 53% (World Bank Data, 2015) as mentioned earlier in Chapter 5. In terms of proportion, it is one of the highest in Africa as Table 6.19 indicates. This can be taken advantage of by encouraging households in most states and cities to patronise PV. However, because the transmission grid voltage in Nigeria is 132KV and 11KV while the grid generation voltage is 33KV (PHCN, 2015), this will pose difficulties for grid integration with standalone modular PV. Meaning that, PV household’s excess generated power cannot be presently exported as in FIT schemes or in the case of net metering, imported.

Table 6.17 Country and percentage of total urban population 2014

Country	**Total Population (2014)**	**Urban Population**	**Urban Population (% total)**
Algeria	39m	27m	70
Angola	24m	10m	43
Egypt	89m	39m	43
Libya	6.3m	5m	78
Ghana	27m	14m	53
Nigeria	177.m	83m	47
S.Africa	54m	35m	64

[28] Note: Nigeria from the 2011/12 data produced 25,695GWh of energy (IEA, 2015).

When grid interconnectivity becomes a reality in Nigeria, this chapter is proof that PV can contribute immensely to national power supply and help unburden the grid network. As the above calculations suggest, in a supportive environment, PV can improve power generation, encourage energy conservation and curtailment, reduce costs and promote environmental sustainability. This chapter has presented the findings of the research and brief implications for Nigeria. Chapter 7 discusses the findings and implications in greater detail while 8 is a short chapter that attempts to design a verified model for rapid PV diffusion in Nigeria based on the collective findings.

Chapter 7

7.1 Discussion and interpretation

This research investigated the barriers to and motives for PV adoption in Nigeria. It questioned the impact government incentives could have on widespread diffusion. It further examined whether large-scale residential PV uptake could lead to increased energy use efficiency. Because this study focused on improving household electricity supply and consequently, their demand, the questionnaire and interviews were designed to capture the opinion of Nigerian households regarding solar PV. The purpose of the chosen research methods and the comparative policy analysis is to use findings to create a model that can serve as a prototype for PV promotion. In other words, to offer more households PV as a reliable option and better alternative to fossil-based power generation that represent the bulk of national supply and end-user generated power.

Parallel accounts of anything often require consistency, especially when that thing becomes, as it is, in the case of green power generation, of great socio-economic and environmental importance. What is essential in such studies, is for the conclusions reached by the researchers to share some meaningful agreement, so that in some ways the results of these related studies can be harmonized. The initially stated propositions in Chapter 1 were tested to ascertain significance. In this chapter the combined results of the research are elucidated upon. Attempt is made to interpret and discuss the findings while establishing links to previous studies where appropriate. It does this to show how the study has answered the research questions and delivered the objectives set out at the beginning of the thesis.

The collective findings from the questionnaire survey and the interviews will be discussed in the following pages. For the purpose of this study, it is assumed that the questionnaire respondents' homes are suitable and compatible with the use of solar PV. Research findings indicate generic, country-specific and PV-focused barriers and drivers. The literature earlier reviewed exposed some of the Socio-cultural, Technical, Economic, Environmental, Regulatory (STEER) determinants of PV adoption identified in this study. The theoretical and practical meaning of the results is illuminated upon starting with household characteristics and the socio-demographic factors impacting PV adoption.

7.1.1 Household characteristics

Gender, household size and age of dwelling did not appear significant on the Spearman's correlation matrix both at 99% and 95% confidence intervals. Planning permission and fear of damage to home also did not show significance. The important household characteristics that correlated to PV purchase decision in Lagos, Nigeria included age, income, education and housing tenure. In general, results correspond with previous studies. However, as was shown in the Spearman's correlation matrix in (Chapter 6) the socio-demographic associations were not particularly strong compared to the economic and behavioural influencers. The effect of socio-demographic profiles are discussed next.

Respondent's Age

The role of age towards PV buying behaviour has long been established. Results suggest that individuals under 30 and those over 64 years of age showed lower acceptance and valuation for PV than those aged 31-64. This group have previously been shown to have lower acceptance and willingness to adopt MGTs (Willis et al, 2011). Of all the age groups, middle-aged people seemed to be the most interested in PV generated electricity. The low WTP for PV by those aged 18-30 years could be explained by the fact that many people that age are more likely to be in an early stage of their career and therefore not have the funds for such investment.

Those aged 31-55 would be mid-career individuals who have a higher probability of earning more than those under 30. Persons over 55 are likely to have more savings with some probably early retirees having worked for a long time. Although older people showed a low WTP overall, they were more likely to pay a higher amount for PV. This group are likely to have finance and would have paid off their mortgage and other such commitments. They also tended to install PV for convenience more than other age groups. This might be interpreted as an indication that older people may find the arduous trips to petrol stations stressful and face greater difficulty operating private generators.

However, the low PV valuation may be because they have become accustomed to the grid power outages or their existing system to the point where they become less interested and more resistant to PV. Older people may also be less aware of PV. Clearly, adoption decision does differ by age. In general, middle-aged groups found PV more appealing and findings corroborate previous researches. Sardianou and Genoudi

(2013) gave accounts of how the middle-aged and highly educated people showed higher WTP for MGTs. Leenheer et al (2011) found that people aged 60 and above revealed a lower intention to generate their own power from microgeneration. Similar findings were also reported by Abdullah and Jeanty (2011) who concluded that older households were less likely to pay for PV, irrespective of payment options. However, findings conflict with that of Sardianou and Genoudi, (2013) and Baskaran et al (2013) who reported a higher adoption propensity with younger people.

Income

The importance of household size and income towards purchase decisions are widely reported. Household size is an important metric in the PV system size to purchase (Komatsu et al, 2011) and the concerned households have to factor in energy demand at times when more people will be in the dwelling. From the combined results of this study, household size did not appear to have an impact on uptake. Income did. Middle and higher income households showed a higher probability to pay for PV than low income groups. Since PV is still a premium technology and has a different investment cycle, it was expected that household earnings would have an effect and be correlated to adoption. A number of academic publications have found this to hold. Oliver et al (2013) showed that higher income earners were more likely to pay a premium for green electricity in Cape Town, South Africa. In Greece, Sardionou and Genoudi reported the same for renewable self-generation (2013). However, income on its own is not a significant determinant of uptake as has been previously reported (Komatsu et al, 2011; Balcombe et al, 2013). If it were, many middle and high income households would own MGTs.

Education

Education is crucial in the acceptance of novel technologies due to its links to level of consumer awareness and general knowledge. Results showed a strong correlation between education and adoption decision. Highly educated consumers had a more positive allure for PV than the less educated. Perhaps, this is to do with the fact that more educated people are more likely to spend the time to search for information and research a technology to aid their decision-making. This finding on the effect of education is in line with that of other researchers including (Sardionou and Genoudi, 2013; Balcombe et al, 2013). Nair et al, (2010) and Claudy et al (2011) also reported a greater likelihood of microgeneration adoption with higher levels of education.

7.1.2 Home ownership, house type and house move

Housing tenure was not revealed as important in the PV investment decision as demonstrated in the survey and interview results, though over a third (36%) of the survey respondents said they owned their homes. It is easy to see why landlords may not interfere with tenants installing PV on their buildings. It is an indication that the tenant is going to be staying in their property for a long duration ensuring a steady flow of rental income for the landlords. Similar to those who were renting their homes, individuals who owned their homes were also affected by power outages. In Nigeria, it is not uncommon for occupants in multi-occupant properties to contribute funds towards buying gasoline for generators so that everyone in the building can have power.

Such a level of cooperation amongst building occupants could help explain why housing tenure may not matter. But to avoid future problems, it would be necessary for the tenants to be protected by changes to rental laws to avoid landlords taking advantage. What is not entirely clear is whether these renting adopters would readily install PV if it were their own home. In other words, would they be concerned about damaging their own property in such a situation? This remains to be seen. In Europe, Leenheer et al (2011) and Sardionou and Genoudi (2013) demonstrated that home ownership was not a significant determinant of MGT adoption decision. However, in rural Kenya, home ownership was a significant factor for households' willingness-to-pay for PV (Abdullah and Jeanty, 2011).

In addition, the questionnaire results indicated that households showed concerns about moving home in the near future. But it was not an issue for those interviewed. This could because of the awareness and knowledge by these adopters that just as PV can easily be mounted on roofs, it is easy to dismantle and move elsewhere if the need arises. While household size was not identified as having an effect on PV adoption, it was observed that the household size in Nigeria seems to be getting smaller. Small (55%) and medium sized (26%) families represented the bulk of the questionnaire respondents. In a study in South-West Nigeria, Chidebell-Emordi (2015) found no significant association between household size, income and electricity supply. Actually, they reported that larger households consumed less energy overall than medium-sized households.

House type was explored due to its importance on amount of solar radiation received, based on orientation and roof space conditions. Households who said they were living in duplexes and bungalows made up the second and third largest category in the dwelling types, next only to those who lived in flats. Individuals who lived in flats represented the highest proportion of questionnaire respondents at 53%. As long as roof space conditions, azimuth angle or orientation issues are ensured, excluding terraced houses, residents of all other dwelling types can effectively deploy PV systems for power generation in their homes.

Type of building impacts PV adoption as the installation has to be made in such a way as to capture maximum solar radiation. Residents of a tenement property would respond to PV differently as the structure of the building can serve to increase or decrease yield due to roof-space limitations and angle considerations. For example, tenement flats - a type of dwelling common in Scotland, places certain limits on the occupiers if they choose to install PV (Karakaya and Sriwannawit, 2015). Residents of these types of buildings found in Festac Town,[29] Lagos (Amuwo-Odofin LCA - under Badagry) would face similar hurdles. Households in detached or semi-detached buildings face lesser constraints in this regard. The large number of building occupants in multi-occupancy buildings can present difficulties. In Ireland, people in detached houses showed higher acceptance of MGT than those in terraced houses (Claudy et al, 2011).

7.2 Willingness-to-pay (WTP) for PV

Compared to households in Asia and Africa, this study showed a very high WTP for PV. Most households stated that they would pay if they received 50-60% discount off a hypothetical 5kWp costing ₦4m (£16,000). In the time following the data collection and analysis, PV costs have significantly reduced due to overcapacity in Asia and the learning curve. This means that the present average cost of a 5kWp system is about half this amount. The extremely high valuation for PV by Nigerian households is a utilitarian one pointing to the subsistence need regular electricity helps to fill.

As a rule of thumb, the accepted budget for energy services is 10% of income (Abdullah and Jeanty, 2011). In Nigeria, The average household spend on electricity was 15% of total monthly income with most households reported to spend about 25% (Chidebell-Emordi, 2015). This also helps to explain the relatively high WTP a premium shown by the questionnaire respondents for improved grid electricity. Few respondents stated that they would be WTP if the Government provides as little as 5-10% discounts for a ₦4m PV system when they had the option to choose any discount level; 60% for instance.

[29] FESTAC is a federal housing estate programme introduced in 1977 at the end of the world Festival of Arts and Culture (FESTAC) event in Lagos (Lagos State Government, Nigeria 2014).

The level of education and utility from PV could have been a factor in the high valuation. It could as well be that some of the surveyed households may have been doubtful of the possibility of the Nigerian Government assisting with PV procurement hence increasing bids. This is because of the general lack of trust for the leaders.

Individuals with university education have been reported to reveal a higher WTP (50% more) for electricity attributes than those without (Amador et al, 2013). The utility derived from solar power has been shown to also be a factor in high WTP (Borchers et al, 2007). In many studies positive attitude towards RETs mean that people are generally prepared to pay extra charges for renewable power (Borchers et al, 2007; Guo et al, 2014; Soon and Ahmad, 2015). While WTP found may appear high when compared to other studies, WTP findings have been shown to depend on the context of the study in terms of location, levels of power outages and culture (Abdullah and Jeanty, 2011; Leenheer et al, 2011).

However, caution should be applied. Results should not be interpreted to mean that most Nigerian households have suddenly become high income earners. Although the Nigerian GDP and economy grew in the years 2003-2014 (Chapter 2) reflecting one of the fastest economic growths in Africa. As at 2014, Nigeria was the richest country in Africa (FT, 2014) so earning power has improved. Notwithstanding, the results should be taken to mean that households are very interested in PV power. One reason it would be easy for households to be prepared to pay a premium is that the power problems have persisted for long with no signs of abating, while the prices of electricity and fuel products have continually increased.

One way to validate mean WTP survey estimates is to compare it with non-market valuation studies or different but comparable studies (Abdullah and Jeanty, 2011; Soon and Ahmad, 2015). Average WTP for green power in Korea was about 3 times the average monthly electricity bill (Yoo and Kwak, 2009; Kim et al, 2012). It is important to note that the mean average WTP given in Korea and other such places is for grid-supplied renewable electricity. Hence, the amounts ranging \$17-\$30/kWp that households agreed to pay in Asia and €16.33 they were WTP quarterly in Greece (Zografakis et al, 2010) was only reflective of green electricity. It does not include ownership of the system as in the case of a residential standalone PV.

7.3 The determinants of Photovoltaic (PV) adoption in Nigeria

The determinants of PV uptake were revealed to encompass a number of internal and external factors. As confirmed from the cumulative results of the questionnaire survey and interviews, STEER factors primarily led to Nigerian households seeking out better alternatives. Table 7.1 is a summary of the determinants of PV adoption in Nigeria. These findings are discussed and elaborated upon afterwards.

Table 7.1 Summary table of the determinants of PV adoption in Nigeria

Dimension	Motivation	Barrier
Socio-cultural	Familiarity Convenience Neighbour PV use	Low awareness Poor maintenance
Technical	Power outage PV design & quiet operation	Incompetence Dishonest technicians Product quality PV limitations
Economic	Cost reduction Access to finance Business promotion Shorter payback time	High capital cost Lack of finance
Environmental	None identified	No recognition and reward for adopters
Regulatory	None identified	Lack of incentives and weak regulatory environment

7.3.1 Factors impacting PV adoption

Socio-cultural barriers

Low PV and electricity awareness were found to be critical barriers. The impression held by many households that electricity is cheap is a huge deterrent. Decades-long subsidies are the cause of this consumer outlook. In addition, the view that traditionally publicly provided service and capital intensive projects are the responsibility of the Government further impacts investment. For consumers that still hold such opinions, PV uptake would be viewed as far too expensive. For this reason, the recent removal of electricity subsidies as earlier stated in this research is a welcome development as it has started to alter this age-long perspective.

In Chapter 3, we saw how the level of ‘electricity literacy’ was low in the USA (Sovacool, 2009). As evidenced in this study; this seems to be a wider phenomenon that constitutes a significant barrier to the diffusion of MGTs. Part of the reason for low electricity awareness can be attributed to the dispatch design of grid power and the fact that in most locations the grid infrastructure is out of sight. It is also responsible for the slow consumer acceptance of the danger posed by overreliance on fossil-fuel sources. In another study, Sovacool et al (2011) also demonstrated how the socio-cultural beliefs and unrealistic expectations by many households in Papua New Guinea has not only revealed disinterest in PV but has led to many failed systems. Little interest and donor dependency were recently reported as barriers to uptake in rural Tanzania and Mozambique (Ahlborg and Hammar, 2014).

Consumer uncertainty about PV did not show a linear link with adoption. Some adopters were unsure, yet proceeded to install PV. Beneath the façade of awareness expressed by some individuals lay doubts about PV’s capacity to provide electricity that could meet everyday household demands. This is not with reference to output efficiency, but disbelief in the technology itself, probably due to its simplicity. It is hard to accept such certainty when one is used to big noisy engines. Low level of consumer awareness can be the result of absence of information, insufficient information or misinformation. Hite et al (2008) observed a high WTP a premium close to total costs for biopower but that most did not have prior information. Poor access to reliable information negatively impacts PV dissemination. Like one adopter said:

> “You know…I was doubtful of the technology so I didn’t want to invest too much money on something I wasn’t sure of.”
>
> \- *S. A.*

This means that notwithstanding the lack of awareness, some people are very receptive to change. Given the high initial costs of a reasonably large PV system, it takes courage to agree to purchase one without fully understanding its functionality or potential. The above innovative adopter installed a 3.5kWp PV capacity which will be relatively expensive; thus very commendable. It illustrates that with proper educational campaigns and enlightenment, consumers can be influenced even in circles where households may have originally displayed indifference towards PV. Positive attitude towards PV influenced WTP in China (Guo et al, 2014). Inadequate knowledge and misinformation of some technicians was also the reason why some adopters thought PV was maintenance free in the same way some marketers advertise solar energy as free energy thereby misleading consumers. An example of such misconception can be seen from the comment here:

> "We do not even clean the solar panels because it doesn't need cleaning."
>
> *- S. A.*

Nigeria can be very dusty presenting a greater need for scheduled cleaning of the panels. Aside this, dust build-up from adjoining building construction works can affect output as occurred in a school building in China (Close et al, 2006). The effectiveness and reliability of solar energy installations is highly dependent on proper handling and maintenance. Panel cleaning should be carried out solely by qualified personnel and costs possibly included in the installation and after-service care arrangement.

Lack of PV awareness is widely reported in literature. People often get exaggerated notions of things they know little about. Tillmans and Schweizer-Reis (2011) detailed how knowledge communications was a problem affecting PV diffusion in Uganda, due to beliefs and misbeliefs stemming from socio-cultural barriers. Earlier in Chapter 3, it was stated that some PV adopters in South Africa misunderstood or were not adequately informed about PV power limits making for unreasonable expectations (Lemaire, 2011). In Rwanda, Crossland et al (2015) demonstrated that low level of understanding, education, system overload and poor maintenance were barriers. Similar trends were confirmed in Asia where below average levels of awareness and knowledge of the potential of PV power impacted adoption (Mondal et al, 2010; Komatsu et al, 2011, Yuan et al, 2011).

Socio-cultural motives

Awareness, familiarity, interpersonal influences and convenience are important predictors of microgeneration adoption. Consumer actions are often based on their level of awareness, knowledge and attitudes. But positive attitudes on its own does not necessarily lead to the acceptance of MGTs. PV does not allow trial before purchase and seeking out information can be difficult without assistance from someone with sound knowledge and expert guidance. Some of the interviewed adopters pointed to how they were influenced by a neighbour or friend. Some individuals who may be interested in switching to modern energy systems may not have all the information at hand. The time and effort to find information online may dissuade prospective customers. Where getting the requisite information becomes problematic, potential investors would have to rely on the dealers and technicians for advice. This pattern is evident in many studies (Baskaran et al (2013). Peers can influence the uptake of PV and on general energy supply choice of consumers (Jager, 2006; Noll et al, 2014). These comments allude:

> "It was a friend who installed my solar panels. There was an agreement that we had so I am 'supposed' to be paying the person by instalments."
>
> *- D. B.*

> "In fact, I have introduced three of my friends to the technician who installed my own."
>
> *- S. A.*

This finding is in contrast to that of Islam and Meade (2013) who pointed out that the level of PV use by neighbours did not significantly affect adoption. Additionally, interest in technology, technical knowledge of PV and energy systems in general proved vital in the adoption decision as uncovered from the interviews. A correlation was found between technical knowledge, education, occupation and PV uptake. Awareness, familiarity and technical knowledge of energy systems plays a crucial role in the decision to buy PV. This finding has previously been underscored in PV adoption and diffusion studies. For example, Leenheer et al, (2011), found that awareness, knowledge, technology affinity were significant drivers. Islam and Meade (2013) noted that technology awareness and technical knowledge are significant factors in adoption probability.

Likewise, the need for comfort and convenience was more of a motive for some:

> "The inconvenience of going to switch on and switch off servers is stressful so cost is not the issue really."
>
> *- D.F.*

Despite the highly positive (92%) responses to the question relating to PV awareness early in the questionnaire, in reality the level of awareness does not seem to be as high. There is a glaring difference between having seen or heard of solar panels and 'knowing' about it. The extremely high PV awareness declared in the questionnaire could have been caused by response bias - a well-known survey problem. Increased PV and energy use awareness through sustained education, informal education and re-education for energy end-users will be required. Providing relevant information using the most practical medium pertinent to the locale is important. The questionnaire results disclosed that the major source of PV awareness for many respondents was TV and radio. This was followed by the internet. Persons who stated having come to know about PV through the internet are more likely to have been informed through mobile devices. It would make sense to utilise more of these mediums in promotion and awareness creation. Many respondents also said they came to know about it from seeing it on building roofs. Increased targeted campaigns can serve to raise more awareness.

With respect to peer effect, although helpful, the disadvantage of 'friends' installing PV was that in the event of problems with the system or components there was not much incentive for the installer to return. The experience and positive attitude of one adopter with short-lived PV depicts:

> "As it is now, it is faulty… It's the battery. But, I still want to use it. It's just that I'm waiting for my friend to come and fix it."
>
> *- D. B.*

This would subsequently mean another failed system. Problems like this demand appropriate credit agreement like that given by some dealers to customers they were acquainted with. The situation points to the urgency of introducing proper regulatory and financial support.

Technical barriers

Practical obstacles related to uptake included incompetence, dishonest technicians, product quality and PV efficiency. Remarks on technical skills shortages, distrust of some technicians and quality were plentiful. Where systems were poorly designed and installed, it led to disappointment. Failure to match household energy demand with the PV device can lead to lower than normal power yield in consequence resulting in dissatisfaction. Allowing unqualified or inexperienced individuals to carry out PV related works is inappropriate.

Consumer lack of confidence in installers and untrustworthy technicians were identified as huge impediments. The perceived quality of a PV module including Balance of Systems (BOS) is an important determinant of investment and vital for a sustained use of PV. Use of deception, changing product labels and providing PV adopting households with lower grade modules, batteries or fewer batteries than required is a common problem in developing countries as found in this research. It is often done by installers and sellers of PV equipment in order to maximise profit. This is an ongoing limitation. Of the 13 questionnaire respondents that said they used PV, ten did not participate in the interviews probably because of bad experiences from failed systems. When people have good use and experience of something they are happy to talk about it.

Similar problems were reported in Kenya (Otieno, 2003), Namibia (Wamukonya and Davis, 2001), and more recently in Uganda ((Tillmans and Schweizer-Reis, 2011), Bangladesh (Komatsu et al, 2013) and China (Karakaya and Sriwannawit, 2015). Undersized PV, overload and technical incompetence hindered uptake in Rwanda and South Africa (Hajat et al, 2009; Crossland et al, 2015).Such practices are the reason some individuals perceive PV electricity as second rate (Stapleton, 2009; Karakaya and Sriwannawit, 2015) and occur because of weak regulation. Subtle forms of disapproval for MGTs threaten PV development and diffusion in every region. The outcome is not only consumer resistance but outright rejection.

Reported delays in completing installation projects and abandoned solar panels arise from poor practices. Just as found in Lagos Nigeria, in Bangladesh, there were cases of abandoned projects and a high prevalence of poorly functioning PV installations (Mondal et al, 2010). The researchers attributed this to its Government’s emphasis on technology-push/market penetration. Although widespread PV use is what is desired, there are very severe consequences when unqualified or underqualified persons engage in installations. As was documented in the United States, PV use presents fire, electrical and mechanical hazards. Typical causes of module fires are poor-cell matching, localised soiling (e.g. bird droppings) and shading (Wohlgemuth and Kurtz, 2012; Close et al, 2006). Improperly connected systems can cause electrical shocks while mounted modules may derail and fall off posing a threat to life. Thus, PV installation calls for serious precautions due to these dangers. Having specially trained installers and PV engineers will be instrumental to the effective and safe installation of PV systems in buildings.

Consumer perception of product quality and technicians impacts adoption. When consumers perceive installers as distrustful, the WTP is seriously impacted (Balcombe et al, 2013). A systematic review by Karakaya and Sriwannawit, (2015) pointed to the doubts by consumers in Ethiopia about PV systems manufactured in Asia, especially China. They said that the consumers preferred to pay a higher amount for systems from other countries. This indicates that there is a need for greater education campaigns for power consumers with added focus on technical skills for installers and a high quality certification process.

Other equally relevant issues were related to information dissemination and awareness creation. Poorly worded messages and misinformation can lead to households mishandling the installation and overburdening the system thus accelerating degradation. This negatively impacts PV market development as the word-of-mouth becomes negative. Likewise, access to technical support is a precondition for a successful diffusion.

PV efficiency limits presented concern for some consumers. Households who were not used to switching off appliances found PV challenging to use. The knowledgeable adopters made the necessary changes without seeing it as constraining. Like this one:

> "My system cannot power all my appliances. If I have to power all my devices, I will need to get more panels. I try to adjust what I am using in order to conserve more power to use at night."
>
> *- F. I.*

From this research, it was noted that when new PV users with low electricity awareness get to this realisation, they begin to draw the connections between their energy consumption and national power shortages. Such insight will make the distant grid more 'visible' and create a scenario where electricity end-users will start to heap less blame on the Government realising their own contribution to the lingering national power situation.

Underlying the statement by some questionnaire respondents that cost factors were the main reason for non-adoption, lies the fear that PV power will not be able to provide adequately for their energy needs. This view is further compounded by the image projected by some utility companies for the furtherance of their business goals. But this limitation posed by PV output presents hidden benefits, as will be explained later. In addition, grid power surges were found to pose an obstacle. The quality of grid electricity can damage appliances for PV users when grid power is suddenly restored. Those who relied solely on LED bulbs reported fewer problems as they noted low impact on such energy-saving appliances.

Technical motives

Technology-related factors were strong drivers. As argued in Chapters 1 and 2, national power supply shortages were largely the reason for the widespread use of auto-generation by most Nigerian households. However, adopters of micro-generation have expectations and one of these is uninterrupted supply. The intention to self-generate power in Nigeria using PV is the direct result of incessant power outages. Quest for reliable power was the most important motivation. When correctly designed, fitted and used, PV's reliability is widely acknowledged.

Questions of affordability arise due to the low-medium income status of many in Nigeria. Nevertheless, the chief motive for PV uptake in Nigeria remains power outages and PV being seen as a solution to this shortcoming. This is proof that households would patronize PV. Willingness-to-pay a higher premium for improved grid electricity services as reported in Chapter 3 pointed to the *value* households place on regular power which is not necessarily based on earnings. This finding is consistent with some previous studies. Unlike the consumer WTP for grid distributed green power a consumer attitude study in Shanghai, China noted that WTP for microgeneration was independent of income. Instead, it was dependent upon how promising the adopters perceived the technology to be (Hast and Syri, 2015). In Kenya, Abdullah and Jeanty (2011) reported a higher valuation for PV and grid electricity by households who suffered more power fluctuations or outages.

However, this research finding conflicts with that of Leenheer et al (2011) who found that power outages were not key drivers of the adoption decision in the Netherlands. The fact that power outages rarely occur in the Netherlands and similar countries explains this. Surprisingly, in agreement, a study in Crete, Greece, revealed higher willingness to adopt green power by individuals who suffered more power failures. Part of the reason given, was that Crete not being connected by cable to mainland Greece, may have received less than usual supply during the time of the study (Zografakis et al, 2010).

Regular supply that PV guaranteed made some adopters consider it more useful, cheaper and consistent than grid electricity and traditional auto-generation. Likewise, households that utilise inverter systems have a greater chance of adopting PV as survey results confirmed. Aside the robust design of PV, a new finding deserving mention was that PV proved to be a smart solution to a tricky situation-the problem of generator use fuel fraud. PV can act as a *safeguard* for its adopters by preventing energy consumers heavily reliant on private power generators from being defrauded of either money or petroleum products. This opportunity is presented if the PV user makes a two-way connection, allowing a smooth switch from their system to grid power and vice-versa.

The fascinating thing about this is that this positive change can be brought about by the adopter with no exchange of words or arguments with the perpetuators. Other than cost savings, solar PV can aid or force behaviour modifications without creating animosity between the owners of the system and their family members or employees. Although the above point was not a stated motive for uptake, using this as a promotion strategy would attract small and medium-scale enterprises (SMEs) or business owners and help them control fraudulent behaviour in relation to energy use. Large homes where such problems exist will also find this attribute beneficial. It may seem obvious that irregular power supply could be a driver of uptake in Nigeria, but it is not apparent when the capital cost of PV is taken into consideration.

Economic barriers

High upfront cost and poor access to finance remains a huge disincentive to wider PV adoption. Initial costs and poor financing constituted the biggest barrier to uptake in Nigeria. Although PV costs have been on the decline, it is still a capital intensive project for many people everywhere. In low-medium income societies and non-liberalized electricity markets, the cost of an average sized solar panel installation is still high. Not many people have the lump sum to pay outright, so this presents a barrier despite interests shown. This is worsened by the fact that, prior to 2012, in Nigeria electricity tariffs were heavily subsidised. This long history of low in-country electricity prices creates a huge challenge for PV systems. The acquired belief that electricity is supposed to be cheap makes it difficult to convince householders of the benefits of PV.

From questionnaire results, the number of households who earlier showed support for PV greatly reduced when they were made aware of the costs and rose significantly when government discounts were offered. In the UK, Balcombe et al (2013) showed that being made aware of microgeneration costs led to withdrawal from the scheme by earlier interested consumers who then expressed preference for nuclear power. Consumer lack of capital required to cover costs impedes diffusion. This is a shortcoming widely reported in unsubsidized markets in Africa (Jacobson, 2007; Abdullah and Jeanty, 2011; Ahlborg and Hammar, 2014). Capital costs and limited funds were hindrances in many parts of Asia (Sovacool et al, 2011; Mondal, 2010; Hast and Syri, 2015) and OECD nations (Lüthi, 2010; Balcombe et al, 2013). Like this adopter rightly said:

> “The cost of acquiring it is the problem. So people prefer to continue using what they have and be spending maybe like ₦2000-₦3000 every day instead of putting in about ₦750, 000 or thereabout for good-sized panels.”
>
> *- F. I.*

The costs of other energy sources impacts uptake as consumers compare other energy options. In this case, choosing between PV and existing sources based on varied measures. Capital costs also made individuals doubtful of the solar PV, preferring to stick with what is known even when they may be convinced that PV is the better option. This problem is referred to as loss aversion[30]. Sticking with the default energy can further arise because of the switching costs (i.e. information search, time etcetera) that the decision carries. In most cases the higher the costs of MGT, the lesser the likelihood of purchase. It is important to also note that it was not only the direct costs that prevented people but also the perception of costs, maintenance/replacement and need to use low-energy devices. Added to the uncertainty many people have about PV output, economic factors present increased disincentive to buy. However, not all the adopters showed price sensitivity.

Also from an economic point of view, capital costs and payback time (PBT) are obstacles to adoption in many locations. However, PBT did not appear to be of significant concern to households and PV adopters in Nigeria. A PBT of less than 5 years for systems under 8kWp was reported. Contrary to other reports PBT was not taken to be important compared to capital costs. PV uptake was more about the intrinsic value to the user and less about PBT. The real worth of an investment to the adopter is a critical factor in the adoption decision (Faiers and Neame, 2006). Statements like, “payback time does not matter to me,” etcetera makes it clear that for many people, PBT was less important than PV attributes in the adoption decision. Of course, this would be different for other types of investors seeking to profit.

In Nigeria PBT of a small PV (<10kWp) has fallen to between 4 to 5 years (Sambo, 2012) but has not significantly created a rush for PV systems. PBT has reduced in many places depending on factors including capacity, energy prices and inflation. Scarpa and Willis (2010) reported a PBT (3-5 years) similar to that found in Nigeria for an equivalent size. In 2012, for a 4kWp system installed in the UK a 9-year PBT was given as ideal (Balcombe et al, 2013). In South Korea, Oh et al, (2013) revealed a preference

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[30] Loss aversion is used to describe the phenomenon of preferring loss to gain (Momsen and Stoerk, 2014).

by households of a PBT of 5-7 years. In Ontario Canada, lower PBT was preferred (Islam and Meade 2013) but this has been shown not to give rise to more adoption in the Netherlands (Jager, 2006). Both of these financial factors can affect consumer WTP for PV systems (Zhao et al, 2012; Balcombe et al, 2013). Findings imply that there are other more important factors necessary for consumer uptake beyond PBT and capital costs.

Economic motives

Energy security and cost-savings derivable from investing in a solar power system were the two most referenced drivers for uptake. Most of the PV adopters considered PV cheaper than central power and auto-generation. This finding shares agreement with that of Hast and Syri (2015) who conducted their research in China. A 6% cost-savings was gained in the UK by PV households (Keirstead, 2007). Some of the reasons behind the views that PV was cheaper than the incumbent power source in Nigeria were related to the recent rise in electricity prices due to subsidy removal. The electricity tariff restructuring and fuel price increases meant that charges rose by over 100% during this period (Financial Times, 2013) making PV near competitive with much lower PBT. Renewables are generally known to be less expensive but only in the long run. Its benefits come with time.

Other points made by the PV users also showed that some felt that the national electricity billing structure was exploitative and not transparent enough. This view led to the perception that they were being overcharged. Additionally, business promotion and access to finance also drove uptake in Nigeria. Access to finance from PV dealers looking to secure a sale was also a key factor. PV was used by this group as a marketing tool as many such investors had it installed on their roofs. Like one of the adopters stated:

> "My solar panels, I got them from a neighbour who is a dealer of PV systems."
>
> - *F. I.*

The above adopter was allowed to pay by instalments. The practice of giving credit to customers in market-oriented locations is not new. In Sri Lanka, Guranatne (1995) and Stapleton (2009) detailed how this helped to create awareness as well as providing assistance to the primarily low income households who could barely afford pico systems let alone an average sized PV. There were other such reports in Kenya (Otieno, 2003; Jacobson, 2007).

The unforeseen outcome of PV being more economical than conventional power sources would be a good selling point for promoters in developing countries. This is particularly because citing environmental issues would not appeal as much as that of cost-reduction to many individuals in this geographic area. Studies show that consumers generally seek gratification sooner than later when faced with positive outcomes, but are ready to defer negative consequences (Abdullah and Jeanty, 2011).

Environmental factors

In Nigeria, the desire for reliable power preceded global warming or climate change concerns. 70% of households said they would install PV due to power outages and 30% for environmental reasons. An above-average environmental consciousness was shown in the questionnaire results but the interview result conflicts it. To some extent this has been reported as normal behaviour in open and closed types of survey questions (Ozaki and Sevastyanova, 2011). But the finding contradicts earlier published reports outside Africa. With the exception of generator noise complaints, most of the adopters did not show environmental concerns or altruism. Actually of all the PV adopters interviewed only three people made reference to issues related to altruism and the environment although most were educated. Notable remarks are given here:

> "If government can encourage people by maybe letting them pay less tax or paying them for not polluting the environment. Since I am using PV systems, if there is any way I can benefit from doing this, it would serve to encourage people. We need something to make people see that their uptake of alternative energy sources are recognised and rewarded."
>
> - *F. I.*

> "I find solar panels very convenient. Using generators can be so problematic. Apart from the noise which is a nuisance, there is constant purchase of fuel..."
>
> - *F. I.*

Where energy, fuel and light poverty is pervasive, lack of environmental concern understandably becomes secondary. To further explain the results arrived at, a study in South Africa (Oliver et al, 2011) recounted the existence of freeriding and the public's view that everybody should contribute equally towards better environmental quality.

Also, Mazar and Zhong (2010) provided evidence that despite showing environmental altruism for RETs by many in advanced countries, individuals who do not purchase low-energy products were generally more altruistic than those who did.

A clearly odd finding that goes to show that mere subscription or open support for microgeneration or RETs does not imply a commitment to environmental causes. This interview finding provides evidence to support this, as all the adopters cited the desire to meet their energy needs as major motivation for uptake, even though some were environmentally conscious. There are exhaustive accounts of ecological concerns and altruistic drivers significantly influencing the interest and subsequent uptake of general renewable energy sources and MGTs in particular. But the large majority of these accounts as to be expected were reported in advanced economies (Rundle-Thiele et al 2008; Salmela and Varho, 2006; Leenheer et al, 2011; Ozaki and Sevastyanova, 2011; Palm and Tengvard, 2011; Islam and Meade, 2013; Guo et al, 2014).

It is well known that some groups still perceive the climate change science argument as propaganda. People would comment openly on things they are passionate about. The findings signify that most people do not feel strongly about environmental matters. If they do, it has not yet come to a point when they would act given their circumstances. Last year, a study demonstrated that while 75% of citizens in highly industrialised economies have a far greater understanding of climate change issues, only half think it is threatening. Of the developed countries surveyed (USA, UK, Australia and Germany) only Japan had 90% environmental consciousness **(**ECEEE, 2015**).**

If people have such high environmental knowledge as was found in Nigeria**,** it would seem to suggest that carbon emissions and environmental degradation are not deemed a threat compared to the need for regular power. It comes perilously close to saying that CO_2 emissions and global warming are unreal. This is precisely the point of statements such as:

> "But, since my PV malfunctioned, I have replaced the energy-saving bulbs with filament bulbs."
>
> *- D. B.*

While noise pollution and improved air quality did not bear the attributes of a significant motivation for uptake, it showed amongst other things that it is a disturbance to generator users, putting them in a somewhat catch 22 situation. For households to get power they require generators but this means having to endure noise in most cases. Not many households can pay for silent power generating plants which are normally sold at ridiculously high prices, never mind the emissions.

7.3.2 Symbolic meanings

PV has been shown to have symbolic meanings for some consumers (Faiers and Neame, 2006; Palm and Tengvard, 2011). In this study, need for recognition was not directly found to be impacting PV uptake. Although there was considerable pride shown as regards PV ownership, PV functionality was more of a decisive factor and an adoptive purpose than prestige-related matters. Thus, for most consumers to start to see PV as symbolising their social class, the technology and traded quality has to improve. What helps to understand this phenomenon is what has been earlier expressed - household subsistence need for stable and regular power. This also makes it easier to comprehend why symbolic and altruistic motives may drive green power adoption and environmentally-friendly practices in richer nations.

However, ownership of big power generating sets is still a means of flaunting wealth in Nigeria. Some homes have separately built small houses for these power systems in the name of shelter. These gasoline generators are environmentally degrading. As the price of PV continues to fall such acknowledgement or recognition needs might arise.
Otherwise, questions would arise such as, why would an individual in a country like Nigeria choose to buy an electric vehicle (EV) at the current costs? A logical answer could be because they are very wealthy, cannot find where to buy gasoline due to national fuel scarcity and that they have reliable and accessible charging points for the EV. These would be the initial reasons. If it were possible for the individual to park the EV in front of their residence (without being vandalised) and that other people can immediately tell it is an EV then it would be worthwhile for those seeking recognition. Large wind turbines would have nearly the same effect and acceptance as EV but it is impractical to install near homes. In this regard, PV has an advantage over other forms of power producing technologies. This striking aspect of PV ‘visibility’ can be harnessed for promotion purposes especially when targeting medium-high income households.

7.3.3 Cooking hob mentality

With growing carbon emissions amidst low carbon intensity (Chapter 2) and *unseen* global warming and climate change, it becomes easier to understand why Nigerian households may not be overly concerned by environmental issues as a prime motivation for opting for a low-carbon path. Its priority is stabilised power supply. For households in countries like Nigeria, it will be almost meaningless to use climate change and global warming as a threat or reason to spark uptake. The only realistic argument to put forward would be that of power stability and security. In the same way, using reliable power supply won't be a convincing enough narrative to stimulate the adoption of micro-renewables by households in advanced economies. While it may appear unreasonable to the environmentalist, it is *like* the natural human response to situations. Carbon emissions and global warming are still concealed from many because like electricity it is presently too abstract and many people are yet to begin to think whether it is real. The attitude towards carbon emissions can be likened to an 'electric cooking hob' which when switched on, even after a long time, does not appear to be hot even though it is.

Regulatory factors

Factors related to the absence of fiscal and non-financial support were widely mentioned in both research methods applied in this study. A majority of the respondents stated that reduced module prices and government subsidy would drive them to buy[31]. Others made mention of poor regulations allowing anybody to enter the business of solar panels, potentially damaging the industry. This has led to unqualified persons taking advantage of the situation for the sole purpose of making profit. Government inaction in cases where its PV projects failed prematurely was also referenced. The non-recognition of individuals who were taking the initiative to install PV was cited as an obstacle and remains a hurdle to wider spread PV adoption in Nigeria. Some examples of relevant comments are given below:

> "If Government can help to regulate the market, it will bring about a reduction in the number of poor quality systems we see in the market today which has affected consumer confidence in PV."
>
> *- D. T.*

> "We should be recognised for not polluting the environment."
>
> *- F. I.*

[31] Note: Some of the enumerated factors could fit into other classifications above but are purposely placed where they are considered most beneficial.

The above references become particularly important in a society where many still believe it is the duty of the government to provide such infrastructure. Since the Nigerian Government has repeatedly shown interest in renewable power generation, at a time when government revenues from crude exports have been regressive (Chapter 2), it is important to use the opportunity to aggressively divert to green power development. It is widely known that Government objectives can trigger or delay adoption. In many countries, there are incentives to help stimulate private sector uptake of renewables (Mendonça, 2007; Dinçer, 2011; Bawakyillenuo, 2012).

Research respondents stated preference for government subsidies over bank loans but preferred bank loans to tax cuts/credits. Import duty waiver for modules and components was also mentioned. Emphatically, households were more attuned to “cash deduction” against tax deduction which was reportedly favoured by households in Greece and the USA (Sardianou and Genoudi, 2013; Zhao et al, 2012). The finding somewhat corroborates that of Abdullah and Jeanty (2011) who demonstrated that given the choice Kenyan households opted for small monthly payments against lump sum.

Incentive support has resulted in Kenya having over 320,000 PV installations (Ondraczek, 2013). In fact, without the availability of supportive promotion schemes, the global PV industry would not have come this far as was demonstrated earlier in Chapter 4 on policy analysis. The simple reason for providing incentives is because of the high upfront costs of PV and its negative externalities. Some of the fiscal incentive mechanisms like RPS/TGCs and net metering would be inappropriate for Nigeria at the present state of grid maturity and electricity markets. Also, since the planned FITs scheme has not fully taken off in Nigeria and the deregulation of the electricity market is not yet finalised, subsidisation of PV and its equipment can be employed to allow for easier outright purchase by households and investors. The benefit of this is that subsidisation of PV modules has led to greater uptake and diffusion than FIT-related schemes (Yamamoto, 2015). However, the most successful policies have been ones where the amount of subsidy was significantly high in relation to the total costs of the system and where the support programme is scheduled to run for a long time (Baskaran et al 2013). This would ensure that the capital cost of PV is reduced making it more affordable. This also means that irrespective of regime changes, there should be policy continuity.

A common theme of many policy schemes used to promote PV across countries is a focus on the size and number of installations. The Nigerian Government should be prepared to start small instead of emphasizing increasing grid capacity or extension.
There is evidence that support for PV in the form of capital subsidies is most effective at the early phases (Oh et al, 2013; Islam and Meade, 2013). These forms of support have ensured steady maturation in large PV markets such as Germany, Spain, Italy, and Kenya.

7.3.4 Relative advantage, complexity and compatibility

In terms of relative advantage over existing systems, the following were found to be critical. In the same way energy consumers check energy prices before switching, potential adopters compare various alternative power generation systems based on the attributes of the innovation. For PV, the fact that it can supply uninterrupted power as well as placing control in the hands of the user is an advantage. Regarding complexity the adopters thought it was easy to use compared to gasoline generators. Likewise, adopters reported finding it compatible with their existing systems and lifestyles. PV has a wide appeal. Its relatively simple but elegant design adds to its acceptance by all the interviewed adopters.

While PV involves user interaction that may be seen by some as time-consuming, it is not a high-involvement technology like Jager (2006) insinuated. Referring to PV as high involvement creates the impression that PV use is burdensome. That would be sending out a distorted message to potential consumers. Experiences of Nigerian users confirm that it is neither time-consuming nor highly-involving. Part of the reason is that most Nigerian households are lifelong traditional self-generators using mainly gasoline generators which are far more highly-involving and inconveniencing to use than PV. A recent Glasgow Housing Association (GHA) study provides added proof that PV is uncomplicated and straightforward to use (GHA, 2015). What made the publication more interesting was the fact that, the remark that PV was found easy to use, was from an elderly resident.

7.4 The hidden benefits of PV power limitations

One of the most interesting discoveries of this research was that household PV adoption leads to increased energy use awareness and subsequently energy efficiency. An almost fivefold increase in energy management was reported by the adopting household's post-PV. They said the presence and location of the meter helped. Like smart meters, PV meter does not only provide useful information for adopters, it served to place control in the hands of the users. This directly impacted household's energy demand and fosters interaction between the users and the system. The energy management opportunity was a function of the high costs of a sizable PV, the presence of an in-house meter and most essentially, the output limits of PV. It is this latter feature of PV that makes for its distinctiveness.

With scarcity, serious reflection begins. The efficiency limits served as a reminder to households that electricity needs to be conserved for regular power to be guaranteed and for the system to function optimally. The meter and limitations were what compelled the users to make the necessary changes. While it may appear as an inconvenience, it was the reason for the savings and the adopters did not find it inconveniencing. Not yet identified in discourses is this "conditioning effect" of PV. In fact, this aspect of PV is often described using negative connotation. For example, the well-known issue of efficiency receives this description. Silicon module and cell efficiencies have exceeded 20% (Mint, 2011). PV output limits is frequently cited as a hindrance. While one cannot deny the existence of output limitations and capacity factor (CF), there seem to be an understated usefulness of solar panels in this regard. Dismal as PV efficiency limits may appear to some published research gives credence to PV's immense prospects.

Since the aim of deploying renewables is to limit emissions and for energy security, PV is one of the best MG technologies for this purpose because it acts as a "conditioner" for households. This notable feature can be best visualised in the energy demands of households in developing nations, where citizens experience long hours of power outages. Having experienced power rationing for a long time, adjusting to PV-supplied power becomes much easier. The long periods of national power shortages have prompted energy frugality which PV deployment helps to preserve. Unlike in OECD countries where citizens are already used to decades of constant power to their homes, the introduction and widespread use of PV becomes difficult because it is certainly not going to meet their very high energy needs. This is probably the reason why the hidden benefits of PV output limitations is yet to be established. It is only such limitations that can help reintroduce de-consumption and reinforce energy use reduction and eventually help accomplish energy efficiency goals. If emissions targets are to be met, there is an urgent need to support widespread uptake and diffusion of residential PV in emerging economies.

Energy reduction from PV use has been previously reported in studies but for different reasons. In the UK, Keirstead (2007) found that the presence of monitors/meters resulted to this saving. Using results obtained from nine social housing residents Bahaj and James (2007) presented proof of a reduction in energy use in PV households but the source of savings was unclear as Stedmon et al (2013) also noted. There is compelling evidence that PV has the potential to introduce and possibly sustain energy use efficiency in households. This is particularly important for households in developing countries where the grid infrastructure is less developed. It will be much easier for such households to form a habit of energy management under such conditions than in societies where grid stability has already been achieved for decades.

7.5 Solutions to the STEER factors impacting energy efficiency measures

The STEER factors impacting residential-scale PV adoption and energy efficiency measures in this study were varied. Results from the combined field surveys create opportunities for improvement. Given the current operating capacity of 6GW, Chidebell-Emordi’s (2015) study is evidence that Nigeria will require at least 108GW to meet the energy demand of its present population. This size of generation plant will cost billions of dollars which the Nigerian government cannot afford (Sambo, 2009; NIPP, 2014). Thus, the role of the private sector towards transforming the power sector becomes vital, as demonstrated in this research. On the surface, advocating for a shift to low-carbon generation using PV at the household scale may seem odd due to capacity factor issues. But to clearly see the benefit demands recognising that collectively, individual actions can result in massive changes. It is vital for the Nigerian Government to begin to see that there is nothing wrong with starting ‘small’. As Schumacher noted early in his masterpiece *“A study of Economics as if people mattered,”* small can be truly beautiful (1973).

Historic experience from unreliable national grid supply would suggest that taking a centralised route will not yield the most benefit. Lessons from the ‘Small Towns’ water project, support the argument that the expansion of grid electrification and capacity enlargement where existing systems are defective, can result in unsuccessful infrastructural projects. An example of such failure is the World Bank water project carried out in Nigeria from 1979-2004 (Hall, 2006). Like Albert Einstein said, "You cannot solve a problem by using the same thought process that created it" (Einstein in Unruh, 2000). Instead communal PV should be given consideration. However, care is required because in such group sharing of natural resources, even renewables, studies have shown the existence of the problem known as the common's dilemma or 'tragedy of the commons'[32]. Jenny et al, (2006) observed this problem in the use of communal PV in Cuba.

7.5.1 Source of funding

Regarding fiscal incentives, a key question that immediately arises is: how will this be funded if the Nigerian Government decides to intervene? One answer would be to borrow from the strategy Germany employed by applying a surcharge of roughly £1 to every electricity consumer's bill (Mendonça, 2007). Another likely question would be: why would the government fund it when the benefit seems to directly accrue to the households, given that there is currently no FITs arrangement? First, the presence of such a support will unburden the grid so it directly benefits the government. Secondly, committing such funds will serve to motivate the Nigerian Government towards creating grid-interconnectivity and a lasting FITs programme to allow export, import and ROI. Leasing schemes should be encouraged for consumers interested in part-ownership. Also, 'PV mortgage' as suggested by Jager (2006) will be promising in Nigeria. This will enable the costs to be spread for the life of the system, making it more affordable. In addition, the banking sector may need to be overhauled to provide micro-credit and finance that enable low-cost borrowing. As a form of fiscal aid, donor organisations may want to consider results-based funding (RBF) for community scale PV in urban areas. Finally, to help check energy consumption, the scenario testing shown in Chapter 8 can be used to set energy demand for households. For instance, maximum consumption could be stipulated as 6000kWh/yr. While going over can be allowed, it should be made to attract a very high surcharge to discourage it.

[32] The common's dilemma refers to how some individuals sharing a resource in a communal setting tend to use more than their fair share while others are made to use less.

7.5.2 Education, quality training and promotion

Targeted awareness creation and education will be vital to cope with the changing face of power generation in Nigeria. It will be necessary to introduce educational campaigns that will help enlighten households on power generation, use and consequences. This should be the case for both conventional and PV power. '*Electricity literacy'* will make individuals start to see connections and begin to appreciate energy use efficiency and sustainability agenda. Consumer education will also help prevent a rebound. Promotion and marketing should be clear and misleading messages avoided.

Likewise, the training received by dealers and installers needs be certified by a trusted body. This will give assurance to adopters that their module design and installation is of exceptional quality. It will also protect the industry. The UK's Microgeneration Certification Scheme (MCS) (Balcombe et al, 2013) is one that can be borrowed for this purpose. As time goes on, making provision for local manufacture of module components will help bring down prices further alongside other learning effects. Local production and use of local content will benefit the economy by creating jobs in this area. By all means local PV production processes need be done using low-carbon sources.

7.5.3 Behavioural changes

It will be necessary to start to encourage behaviours that conserve energy. Personal choices, occupant knowledge, habits, routines, motivation and control all impact energy efficiency measures in dwellings (Hargreaves et al, 2013). Incorporating the 'human factor' into PV meter design will help create more awareness (Buchanan et al, 2015). Providing comprehensive information and guidelines will aid energy use decision-making and foster engagement by the PV adopters. Household behavioural responses to MGT is said to be positive when it raises household energy knowledge, reduces GHG emissions, does not create further burden for fuel poor households and contributes to securing grid power (Keirstead, 2007).

Promoting PV using the FITs policy should not be seen as a defeat of energy insecurity and environmental degradation, without the inclusion of strategies that would make households change their energy use behaviours. In chapters 3 and 4, it was shown that using FITs and RPS/TGCs to stimulate diffusion is not the same as using it to alter consumer habits for better energy consumption. This would mean that feedback meter will be obligatory in every installation. In designing PV meters it will be important to consider younger members of families. By incorporating nice melodies/tunes or using smileys, younger members of households and children can be made to embrace energy management. For example, a good level of energy use can be represented with a smile while overconsumption can be symbolised using a frown. In this way, families can plan to use the modules for high energy demand tasks during peak power production.

7.5.4 Import duty cuts and ban of inefficient appliances

Increased support for the use of energy saving appliances starting with the gradual phase-out of traditional light-bulbs will be required. The Nigerian Government may want to place a ban on the importation of second-hand refrigerators into the country like Ghana did (BBC, 2012). This can be extended to include other second-hand appliances like energy inefficient air conditioners. Import duty cuts will reduce total module installation costs, while enabling importers to make reasonable profit without resorting to poor business practices. For this to work, the Government will need to liaise with importers of these products and provide adequate monitoring.

7.5.5 Building changes and the need for automation

Achieving energy efficiency will entail changing the way buildings are constructed. The Nigerian Government can mandate the house-building sector to integrate PV in new buildings. This could be similar to the UK Merton rule which was very successful. In this way, PV would be a common feature of newly constructed buildings. Building designers and developers could liaise with PV sales and installation firms, as was effectively done in Japan (Shum and Watanabe, 2009). Involving the building construction industry will help establish standards while at the same time promote PV usage.

Of necessity, new buildings have to be made as energy efficient as possible. In addition to mandating PV use, architects and building developers have to include not only active but passive means of cooling and heating. One other way to hasten PV uptake, is to encourage the development of estates or similar blocks of buildings that would allow standardization of the modules (against customization) so that it fits with little need for alteration. In this way, it will be treated as a manufactured technology. But this would not be enough, hence, support for PV utilisation by residents of older buildings will be necessary.

Furthermore, utilising automation will be necessary for times when individuals forget to switch off appliances. There would be instances where, despite best intentions and efforts, households do not remember to switch off appliances. To prevent landlord-tenant disputes, rental laws have to be amended to include landlords' acceptance of such alterations to land and property. Lastly, the Nigerian Government should lead by example by introducing PV as a key feature of its building development projects. Ministries, Government buildings, newly built and planned low-cost housing schemes for citizens can all benefit from PV.

7.5.6 Generator amnesty

The Nigerian Government could further opt for "*generator amnesty*" by paying petrol and diesel generating households to return their generators. Using '*carbon exchange*' as a way of withdrawing these harmful engines from society, they could first target diesel generator users, as these tend to be larger systems with greater emissions. It would be unrealistic to attempt to withdraw private generators from certain users. For instance, road construction and maintenance workers will still need to be able to generate power on the spot for roadworks but they can be made to use more efficient power generation engines.

7.5.7 Research into power storage and cheaper module types

R & D in batteries that can retain power for weeks or months will be a worthwhile investment, so that during times of shorter solar insolation the batteries can sustain households for much longer. To further make PV more affordable, other less expensive module types to silicon based cells can be researched to improve their efficiency. Thin film PV makes use of fewer materials and is low-cost. The same applies to Organic Photovoltaics (OPV) which is also cheaper than silicon cells with a much shorter PBT (Menzies et al, 2009). Their lower efficiency compared to crystalline cells is what currently makes them unattractive.

7.6 Summary of discussion

The barrier to adoption and its associated complexity comes from unfavourable government energy policy and energy use at the disaggregated level of the households which this study is primarily concerned about. PV adoption apathy is further determined by other factors like households or the wider energy consumers. Household inertia and resistance to solar PV takes the form of wanting to keep the 'confirmed' power supply source even when it might be the most expensive and least rewarding option. Loss aversion makes potential consumers decline to acquire gains by preferring losses due to the intense fear of the supposed gain from the switch not materializing. Overall, it is detrimental and impacts not only fossil-fuel power sources but also PV and other green power sources as well. Favourable PV policies to minimise costs of acquisition will help to change this attitude towards microgeneration.

Having increasingly showed interest towards diversifying the Nigerian power sector through policies like the REMP, it is time to act. Renewable energy '*policy ambivalence'* would continue to stall plans, targets and the transition towards a low-carbon society. Promoting increased consumer awareness, provision of a stable regulatory platform for industry participants, and supporting the current early adopters would be crucial to save the budding sector. This could be a way for the Nigerian Government to gradually start to make electricity end-users understand that its responsibility is no longer to provide power but rather to facilitate the process of infrastructure provision (Chapter 3). Moreover, increased PV use will be needed to prevent *'carbon copy'* in Nigeria.

7.7 Implication of findings

Research findings will be relevant to most sub-Saharan countries because of similarity of contexts. Despite being applicable to the context mentioned, findings still have implication for energy efficiency measures currently applied to residential buildings in OECD countries and for the wider climate change mitigation initiatives. For example, a key question that arises is, would the current reliance on voluntary household participation in microgeneration uptake be sufficient to enable nations meet their carbon reduction targets? Thus, findings illustrate the role urban households in developing countries are playing and can play towards cleaner power production and the investment opportunities it presents.

In this chapter evidence has been provided that the hindrances to PV adoption can be removed with regulatory reforms and favourable incentives. It has also proven that PV can make households begin to see the links between their energy demand and power shortages. In other words, that PV can bring about energy use efficiency in dwellings. The following Chapter 8 presents the framework for rapid diffusion in Nigeria and describes the energy efficiency cycle created by PV adoption.

Chapter 8

8.1 The verified model for rapid PV adoption and increased energy efficiency

To enable much easier decision-making for electricity end-users and to allow policymakers to implement incentive schemes, this chapter addresses ways by which residential PV can be supported for optimal outcome. Research methods adopted in a study do not only lead to the development of verifiable theories but also one where the findings obtained can have practical application (Amaratunga et al, 2002). This practical use involves designing a decision-making tool for implementing PV policies. It is in fulfilment of the fifth and last objective of this research as given in Chapter 1, Section 1.4.3 and in line with the utilitarian function later promised (Chapter 5).

Therefore, this chapter primarily attempts to create a PV adoption model for low, medium and high income households to assist the Nigerian government and policy-makers of similar countries to promote and implement PV diffusion programmes. As literature review demonstrated, most studies on promoting low-carbon societies either concentrate on technological improvement or behavioural modifications. A more combined approach is required to tackle the energy security and climate change challenge. This research investigated the barriers to and drivers of household-level PV adoption. Although technology-oriented and PV-focused, it is also user-centred. It examined the supply and demand side in order to identify the most optimal strategy to improve electricity supply, raise more consumer PV and energy use awareness.

In the previous chapter, it was shown that domestic PV adoption leads to increased energy use efficiency. It was stated that high capital cost of a large PV module, feedback from meter checks and particularly PV efficiency limits were the chief reasons for adopting household energy conservation. In this chapter, more of these will be discussed, especially the study's contribution to policy and industry. Building on the findings from Chapters 2-7, the PV efficiency cycle shown in Figure 8.1 was developed. Following this, the steps taken before the PV promotion model was designed will be presented. Although the verified model can be said to be generally self-explanatory, it is briefly explained to make its usefulness clearer.

8.2 The PV energy efficiency cycle

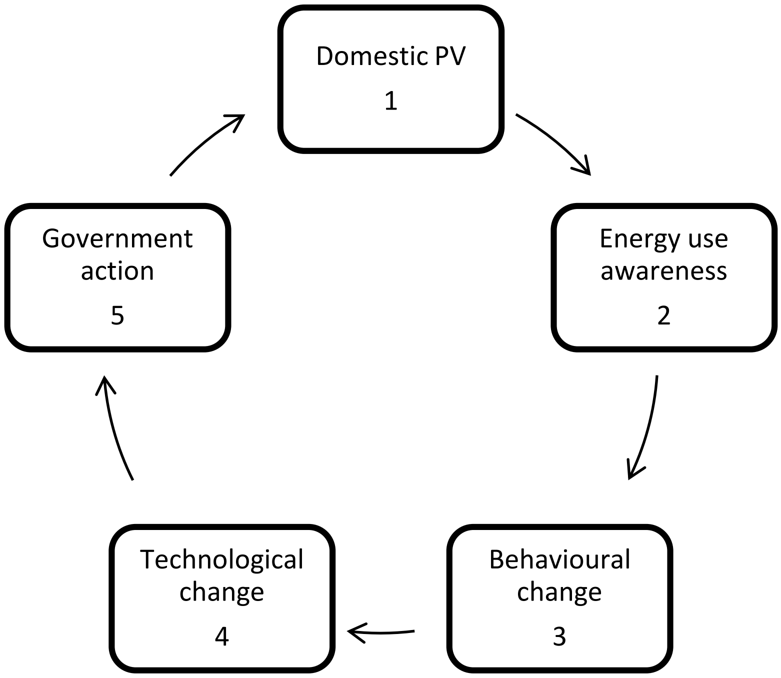

Figure 8.1 PV energy efficiency cycle

The continuous processes illustrated in Figure 8.1 serve to indicate the crucial steps that PV-adopting households take to achieve energy use efficiency. Starting from Step 1 when the PV is installed, the PV electricity generating households start to notice the improvements to their energy demand which PV has enabled. This excitement stems from the fact that it may be the first time the users have had uninterrupted supply for a while, without the need to use alternative sources like fossil-based generators that require constant fuel purchases. This excitement, plus meter/monitor checks, draws the users closer to the workings of a PV unit.

Clockwise from point 1, at Step 2, PV design limitations start to bear on the users as they realise that they cannot use their PV for every appliance but mainly for essentials. Due to its non-dispatch design, the users then realise that they have to conserve power to allow the efficient running of the device. At this stage, energy use management becomes the sole prerogative of the PV adopters as they make sure that unnecessary plugging in of every household appliance is avoided and discouraged. Increased electricity and energy use awareness arises from the restrictive use of PV and controls overconsumption habits. This new energy use awareness creates the "conditioning effect" resulting in behavioural changes (Step 3) which is the most important role of a

PV module as it pertains to energy cost savings, efficiency and environmental sustainability.

It thus behoves the households to begin to search out other ways they can reduce consumption in order to make the device function more effectively and efficiently. This leads to greater awareness and the consideration and uptake of modern power saving household appliances and building technologies (Step 4). Also, other possible avenues to minimise energy consumption is sought. Here, energy efficiency ideas like purchasing more energy saving appliances and retrofitting the building for passive cooling and heating, to allow for natural airflow and solar gains to the dwelling, become more realistic. This is a form of climate change building adaptation that PV utilisation can stimulate.

Some households would voluntarily make these building changes having had the opportunity to observe first-hand the energy dynamics of a PV unit. For other non-adopting households the government can assist with support instruments (with particular emphasis on efficiency) to encourage PV adoption. It will be necessary for the Government to mandate the building construction industry and private developers to incorporate the widely appraised Passivhaus standards or something similar (Step 5) in new buildings as earlier stated in Chapter 7, to help ensure smoother operation of low-carbon initiatives like residential PV use.

It should be noted that not in all cases is the PV cycle sequential as it appears on the diagram. For example, those individuals with high technical knowledge might bypass the energy awareness and conditioning phase (behavioural change) by deliberately installing their PV to be used with certain selected appliances in the home. They could include a PV controller or exclude power guzzling devices like multiple A/Cs from the unit to better manage the system. Nevertheless, their use of PV will still demand that they routinely check their energy consumption as solar radiation and daylight intensity varies daily and hourly. In the absence of very good storage, solar intermittency may require that even when there is pre-set connections the adopting households disconnect or shed non-critical load from the unit. Notwithstanding, the point of the cycle is that most adopters will pass through the 4 initial phases and then decide if there is further need for additional adjustments such as building retrofit to accommodate the proper function of the solar panels.

The above shows that a simple decision to install solar panels in order to improve power supply to a home can bring about a whole range of unforeseen positive behavioural changes and long term benefits for the adopting households and society at large. The triple benefits of energy cost savings, efficiency and socio-environmental sustainability, materialize as a result of PV's elegant design. These benefits should be taken advantage of by policymakers to help ensure energy security and combat climate change effects, which is the ultimate goal.

As previously shown in the literature Chapter 3 and the discussion Chapter 7, household PV uptake can result in increased energy use efficiency as also found by Keirstead, (2007) and Bahaj and James, (2007) and reported by Stedmon et al, (2013). From this research, the steps illustrated in the PV efficiency cycle were developed following the interviews with the PV adopters. For example, in explaining how they conserved power, many of the adopters commented on unplugging some appliances like air-conditioners or deep freezers during times of low production. Others stated that they started purchasing low energy light-bulbs and refrigerators to make the system function well.

The steps demonstrated in the PV efficiency cycle above would mean that the annual energy yield of 7843.39kWh/yr arrived at from the RETScreen computation (Appendix H) and the PV dimension calculations (see section 8.3 below) would meet most of the average household's energy needs. This will be the case especially if the installation comes with intelligent systems like the controller as detailed in the schematic drawing (Appendix J and K) to help shed non-critical loads or safely shut down the system at times of reduced generation. The PV dimensions covered aspects including area of a unit of PV, number of PV units to be mounted and total area (m^2) for installing the 5kWp PV system.

8.3 RETScreen data of PV annual yield for Lagos, Nigeria

MONTH	kWh/m^2/d	Number of Days in the Month	Multiplied by the Number of Days
January	5.28	31	163.68
February	5.49	29	159.21
March	5.46	31	169.26
April	5.21	30	156.3
May	4.76	31	147.56
June	4.04	30	121.2
July	3.95	31	122.45
August	3.98	31	123.38
September	4.09	30	122.7
October	4.55	31	141.05
November	4.95	30	148.5
December	5.17	31	160.27
		Annual kWh Total For 1m^2 of PV unit	**1735.56**

Area of 280Wp PV (1.956 x 0.992)m^2	Array of 280kW in a 5kW System	Total Area of 5kW PV System(m^2)	kWh/29.1m^2/year	*Efficiency of 280kW PV Panel	Generated kWh/29.1m^2/year
1.94	15	29.1	4763.088	15.53%	739.71
1.94	15	29.1	4633.011	15.53%	719.51
1.94	15	29.1	4925.466	15.53%	764.92
1.94	15	29.1	4548.33	15.53%	706.36
1.94	15	29.1	4293.996	15.53%	666.86
1.94	15	29.1	3526.92	15.53%	547.73
1.94	15	29.1	3563.295	15.53%	553.38
1.94	15	29.1	3590.358	15.53%	557.58
1.94	15	29.1	3570.57	15.53%	554.51
1.94	15	29.1	4104.555	15.53%	637.44
1.94	15	29.1	4321.35	15.53%	671.11
1.94	15	29.1	4663.857	15.53%	724.30
Annual kWh Total for an array of 15, 280kW PV system[33]					**7843.39**

8.4 Creating the verified model for rapid PV diffusion

In the design of the verified model, all the key STEER factors impacting PV adoption were considered. After weighing the choices, so as to effectively create a good model, it

[33] All data on dimensions except Efficiency was obtained from EMNI Solar Abuja Nigeria (Appendix I). Efficiency data derived from Solarmango, (2016).

was decided that levels of power outage and cost be accorded the heaviest weight. For the same reason and because the tool is meant to be for grassroots a more realistic yardstick reflecting earnings in Lagos Nigeria (Chapter 2) was used as household income bands. Also, the

8.5 Levelized Cost of Electricity (LCOE) for a 5kWp PV system

LCOE or Levelized Energy Cost (LEC) is a benchmarking tool. It is the net present value of the unit cost of electricity over the lifetime of a generating asset (Branker et al, 2011). Using RETScreen software data (Appendix H) and a 5kWp PV system dimensions data from EMNI Sustainable Solar Abuja (Appendix I), it was shown that a 5kWp PV system in Lagos, Nigeria would generate 7843.39kWh/year at roughly 21.49kW per day. Also, the PV lifespan of 24 years used here in the LCOE calculations is consistent with studies (Branker et al, 2011).

$$\text{LCOE} = \frac{\text{Sum of costs over lifetime}}{\text{Sum of electrical energy produced over lifetime}}$$

$$\frac{\sum_{t=1}^{n} \frac{It + Mt + Ft}{(1+r)t}}{\sum_{t=1}^{n} \frac{Et}{(1+r)t}}$$

Where:

It: investment expenditures in the year *t*

Mt: operation and maintenance expenditures in the year *t*

Ft: fuel expenditure in the year *t*

Et: electrical energy generated in the year *t*

r: discount rate

n: expected lifetime of system.

Therefore:

It: 1,938,000 Naira[34] (one-off investment expenditure) + 600,000 Naira (total cost of replacement of batteries every 8 years)[35].

Mt: 20,000 Naira

Ft: 0

[34] Nigerian currency represented by the symbol ₦
[35] Price quote attached in Appendix E

Et: 7843.39kWh/year

r: 10% (nominal)

n: 24 years

In the absence of a reliable national discount rate (*r*), a 10% nominal (*r*) was applied to the calculation. To take every possible unique factor (e.g. year-on-year inflation, depreciation etc.) into consideration would require that the above is calculated for every year for 24 years and summed up. Also, while maintenance cost of ₦20, 000 per year is used, PV is largely maintenance-free (Bahaj, 2005). Detailed below are the LCOE for a 5kWp PV and a 6.5kVA diesel generator.

LCoE For 5kW PV System @ 10% Discount Rate

Year	Investment Expenditure *I*(Naira)	Time value of *I.= [It/(1+r)^t]*	Maintenance cost *M*(Naira)	Time value of *M. =[Mt/(1+r)^t]*	Fuel costs *F*(Naira)	Time value of *F.= [Ft/(1+r)^t]*	Electrical Energy Generated *E (kWh)*	Time value of *E.= [Et/(1+r)^t]*
1	1,938,000.00	1,761,818.18	20,000.00	18,181.82	0.00	0.00	7,843.39	7,130.35
2	0	0.00	20,000.00	16,528.93	0.00	0.00	7,843.39	6,482.14
3	0	0.00	20,000.00	15,026.30	0.00	0.00	7,843.39	5,892.85
4	0	0.00	20,000.00	13,660.27	0.00	0.00	7,843.39	5,357.14
5	0	0.00	20,000.00	12,418.43	0.00	0.00	7,843.39	4,870.13
6	0	0.00	20,000.00	11,289.48	0.00	0.00	7,843.39	4,427.39
7	0	0.00	20,000.00	10,263.16	0.00	0.00	7,843.39	4,024.90
8	0	0.00	220,000.00	102,631.62	0.00	0.00	7,843.39	3,659.00
9	0	0.00	20,000.00	8,481.95	0.00	0.00	7,843.39	3,326.36
10	0	0.00	20,000.00	7,710.87	0.00	0.00	7,843.39	3,023.97
11	0	0.00	20,000.00	7,009.88	0.00	0.00	7,843.39	2,749.06
12	0	0.00	20,000.00	6,372.62	0.00	0.00	7,843.39	2,499.15
13	0	0.00	20,000.00	5,793.29	0.00	0.00	7,843.39	2,271.95
14	0	0.00	20,000.00	5,266.63	0.00	0.00	7,843.39	2,065.41
15	0	0.00	20,000.00	4,787.84	0.00	0.00	7,843.39	1,877.65
16	0	0.00	220,000.00	47,878.41	0.00	0.00	7,843.39	1,706.95
17	0	0.00	20,000.00	3,956.89	0.00	0.00	7,843.39	1,551.77
18	0	0.00	20,000.00	3,597.18	0.00	0.00	7,843.39	1,410.70
19	0	0.00	20,000.00	3,270.16	0.00	0.00	7,843.39	1,282.46
20	0	0.00	20,000.00	2,972.87	0.00	0.00	7,843.39	1,165.87
21	0	0.00	20,000.00	2,702.61	0.00	0.00	7,843.39	1,059.88
22	0	0.00	20,000.00	2,456.92	0.00	0.00	7,843.39	963.53
23	0	0.00	20,000.00	2,233.56	0.00	0.00	7,843.39	875.94
24	0	0.00	220,000.00	22,335.63	0.00	0.00	7,843.39	796.30
		∑=1,761,818.18		∑=336,827.30		∑=0.00		∑=70,470.85

LCoE(PV) = 29.78/kWh

Thus, LCOE for PV with a lifespan of 24 years = **₦29.78k/kWh**.

Note that the current electricity tariff for domestic electricity in Nigeria is ₦24/kWh (PHCN, 2015), making PV generated-power to be near grid parity. It is established that PV has reached grid parity in many locations (IEA, 2014). However, its cost advantage is dependent on the system staying fully functional for as long as advertised. Therefore, PV is only cost competitive if it remains functional for as long as marketed. There are reports of PV lasting up to 30 years (Branker et al, 2011) so it becomes important for this to remain the case in every installation.

From RETScreen output, it was estimated that a 5kWp system in Lagos, Nigeria will generate 7843.39kWh/year. This is a reasonable yield and is particularly important for energy efficiency reasons. That is, so as not to encourage overconsumption. In the UK, a 4kWp system in the Westminster area generated about 3820kWh/ year. While the same capacity in Stirling, Scotland generated about 3180kWh/year (Energy Saving Trust, 2016). To take account of learning effects, which results in lower total costs of a PV module over time, 10% depreciation could be applied to the total expenditures calculated for each year.

8.6 LCOE for a 6.5kVA Diesel generator

To arrive at useful conclusions it was necessary to compare LCOE with that of diesel power generation.

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}}$$

$$\frac{\sum_{t=1}^{n} \frac{It + Mt + Ft}{(1+r)t}}{\sum_{t=1}^{n} \frac{Et}{(1+r)t}}$$

Where:

It: investment expenditures in the year *t*

Mt: operation and maintenance expenditures in the year *t*

Ft: fuel expenditure in the year *t*

Et: electrical energy generated in the year *t*

r: discount rate

n: expected lifetime of system.

Therefore:

It: ₦150,000 (one-off investment for a 6.5kVA gasoline generator) + ₦15,000 (cost of installation and labour)

Mt: ₦1, 500 per month (1,500 x 12months) =₦18,000 a year

Ft: 2.2Liters per hour at full load. If the generator runs for 8 hours a day, then daily fuel consumption will be 2.2 x 8 =17.6L.

17.6 x 365 days = 6424L a year.

At today's cost of ₦86 / L, it gives: 86 x 6424L =₦552,464,00

Et: If the generator runs for 8hrs every day and is able to run at 80% of its rated capacity (0.8 x 5.2kW = 4.16kW), then it generates 4.16kW x 8hrs (33.28kWh of energy/day). So, in a year it generates 365 days x 33.28kWh = 12,147kWh of energy.

r: 10% nominal

n: 5 years

LCoE For 6.5kVA (5.2kW) Gasoline Gen set @ 10% Discount Rate

Year	Investment Expenditure *I*(Naira)	Time value of *I.= [It/(1+r)^t]*	Maintenance cost *M*(Naira)	Time value of *M. =[Mt/(1+r)^t]*	Fuel costs *F*(Naira)	Time value of *F.= [Ft/(1+r)^t]*	Electrical Energy Generated *E (kWh)*	Time value of *E.= [Et/(1+r)^t]*
1	165,000.00	150,000.00	18,000.00	16,363.64	552,464.00	502,240.00	12,147.00	11,042.73
2	0	0.00	18,000.00	14,876.03	552,464.00	456,581.82	12,147.00	10,038.84
3	0	0.00	18,000.00	13,523.67	552,464.00	415,074.38	12,147.00	9,126.22
4	0	0.00	18,000.00	12,294.24	552,464.00	377,340.35	12,147.00	8,296.56
5	0	0.00	18,000.00	11,176.58	552,464.00	343,036.68	12,147.00	7,542.33
		∑=150,000.00		**∑=68,234.16**		**∑=2,094,273.22**		**∑=46,046.69**

LCoE = **50.22/kWh**

LCoE = *[It/(1+r)^t] + [Mt/(1+r)^t] + [Ft/(1+r)^t]* / *[Et/(1+r)^t]*

Hence: LCOE for a 6.5kVA diesel generator = **₦50.22k / kWh**

Therefore, LCOE for an equivalent sized diesel generator to the 5kWp PV is ₦50.22k/kWh. This is about £0.20/kWh. Figure 8.2 represents the above scenario testing of the LCOE for a 5kWp PV and 6.5kVA diesel generator plus grid electricity costs/kWh and lifespan. Of the different power generation sources examined (PV, diesel generator and grid power) PV has the least cost/kWh compared to diesel generation but a little costlier than base load electricity. Also, although grid power has a longer lifespan it is environmentally unsustainable.

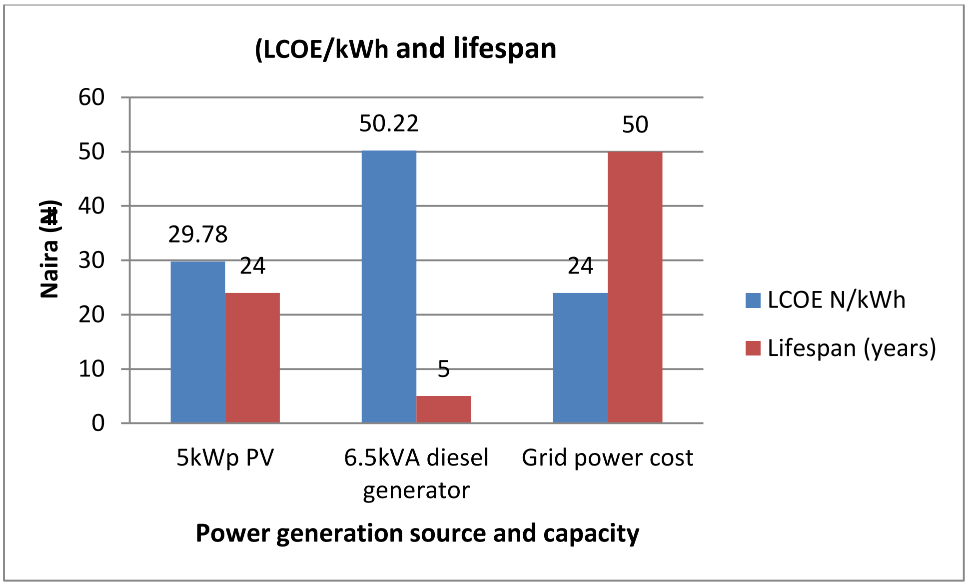

Figure 8.2 LCOE scenario tests for PV, diesel generator and grid power

8.7 The verified model for rapid PV diffusion in Nigeria

To create a useful tool that can aid PV promotion, a number of key variables obtained from the questionnaire and interview findings and policy analysis were examined and the most significant ones applied to the model. As can be observed in Figure 8.3 the selected variables include power outages (levels of grid supply received), alternative sources (fossil and green power) including inverter use, electricity costs/kWh, income, awareness, PV sizes for different household groups, communal PV, financing, environmental consciousness, energy conservation and education while annual/monthly solar PV yield was estimated using RETScreen data. The LCOE calculated from a 24-year PV lifespan (₦29.78/kWh) was used to compare with that of existing power sources. Using these measures it was possible to draw up the verified model for rapid PV diffusion as shown in Figure 8.3. This model places no distinction on a particular group. It can be used by the Nigerian Government, policy makers, and PV designers. It can also be used by SMEs and directly by householders for PV adoption decision-making.

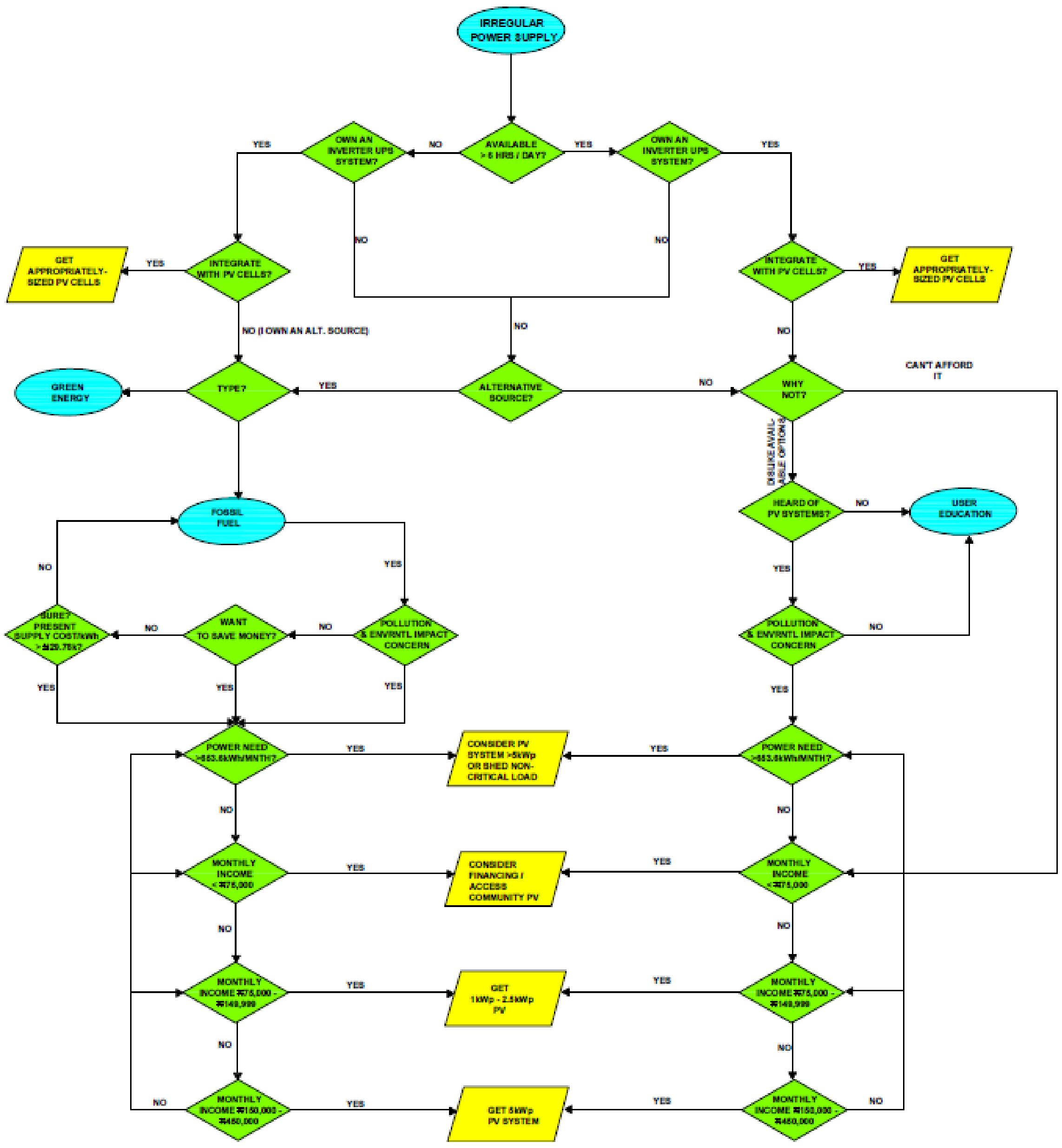

Figure 8.3 A verified model for rapid PV diffusion in Nigeria

8.8 Summary and conclusions

In this model, an estimate had to be used based on a number of parameters but with a small margin for error. LCOE for green power and fossil-fuel has helped create a guide for PV promotion. In the above model, the PV side (right) is analogous to the fossil-fuel side (left). This framework can be modelled using a computer programme to draw up an algorithm that will allow users to enter data such as costs of their existing electricity, income and household size. It will then generate a suitable PV module for the potential adopter. In this way, anyone can find the model easy to apply.

As a way of demonstrating practical functioning and to ensure that the model operates in the intended manner, it was considered necessary to 'test' it. A total of 14 households from Nigeria were asked to do the trial. Of this number, 12 found it straightforward to understand and apply, 1 household needed help occasionally and the remainder did not understand it. Most of the households who participated have university degree in science and engineering. This outcome, while positive does also point to the need for increased *electricity literacy* as earlier mentioned. It is also interesting to find that a 5kWp PV system can meet almost all energy needs of many households. Furthermore, the annual output of 7843.39kWh/yr is much higher than the Minimum Energy Poverty Line (MEPL) of 3068kWh/yr given by Chidebell-Emordi, (2015). However, of necessity, the module has to be properly designed, installed and operated. Also, as an integral part of the PV installation, a competent but inexpensive load manager can schedule the appliances to come ON and OFF in such a way that the total load requirement at any given time fits into the 5KW window.

This chapter is additional proof that instigating rapid PV diffusion will require a radical approach entirely different from paths previously followed. Regular and reliable electricity will enable households to move out of '*light poverty'* and energy poverty and engage in economically useful and socially productive activities, as they live in cleaner environments. Aside providing fiscal incentives to make PV more appealing, there will be need for better regulation so that highly qualified technicians, high quality materials, and installations will be the norm. Also, more consumer awareness need be created. It is believed that this awareness and knowledge would increase PV uptake and help positively change energy generation and consumption behaviour. This verified model will be mainly useful for non-liberalised electricity markets or societies where public services are still centrally provided. The next chapter (9) concludes this research with recommendations on future studies based on the outcome of the research.

Chapter 9

9. 1 Conclusions and recommendations

PV power represents an interesting episode in the history of power generation in Nigeria. At the beginning of this thesis it was stated that many Nigerian households are *'experienced'* conventional self-generators. This study has demonstrated that this experience is slowly being transferred to modern auto-generation in the form of inverter use and most importantly, solar PV uptake. This experience can be taken advantage of for energy security, efficiency and carbon mitigation drive. Considering the early stage of national grid infrastructure development in Nigeria, PV presents a latecomer's advantage that can be exploited for power security and energy efficiency.

Using adoption and innovation diffusion theories and the WTP, coproduction and self-help concepts, it was shown that PV can lead to improved household behaviour towards energy conservation. That is, that PV can create energy use efficiency arising mainly from its power limitations and feedback meter. This answers hypothesis 2 (Chapter 1, page 6). To provide answers to hypothesis 1, it was also confirmed that the hindrances to PV deployment by urban residential sector can be removed by appropriate support policies. Thus, as hypothesized, findings were positive. Both the quantitative and qualitative analysis (questionnaire survey and the interviews) provide proof that political and regulatory intervention is required for widespread PV adoption. Government intervention as a prerequisite is extensively reported in studies.

In Chapter 7, detailed discussion of the findings and the theoretical contribution was presented. In Chapter 8, the PV efficiency cycle was demonstrated and a verified model was designed for rapid diffusion based on the findings - a practical contribution. Other aspects addressed in this chapter are the limitations of the study and opportunities for future research. This research deviated from the norm in the following ways:

- It has examined the barriers to urban household-level PV uptake in Nigeria.
- It has investigated the motives for PV adoption in urban Nigeria.
- It has analysed the use of incentive support policies to stimulate diffusion.
- It has explored the potential of PV towards energy use efficiency.
- After identifying answers to all the above, it has provided a practical tool and framework to facilitate PV implementation for widespread adoption.

9.2 Achieving the objectives and research contribution to theory

Objective 1 was to undertake an independent investigation as to the barriers to, and motives for, household-level PV adoption. The above objective was answered in Chapter 3.

To fully understand the factors impacting uptake it was considered necessary to examine established theories on adoption, consumer response studies, WTP, socio-technical systems and innovation diffusion from individual, industry and national perspectives. Given the stage of economic development in Nigeria, where the PV industry is still unsubsidised, the lesser used concepts of coproduction and self-help were explored. Irregular, unreliable electricity hinders socio-economic progress. Although in the last 30 years many studies have sought to solve the national power supply challenge in Nigeria, they have met little success. Most of these studies have ignored the potential of microgeneration technologies (MGTs) because of a focus on large central power. But the link between MGT and an improvement in end-users supply, demand, savings and environment has been repeatedly documented. From the reviewed literature, the barriers to PV uptake were found to be multifaceted and interlinked. Likewise, the motives for uptake were varied but interrelated. Some of the factors uncovered from previous studies in Chapter 3 included: path dependency, behavioural factors, low level of awareness, lack of funds, high costs of PV as obstacles and energy security, altruism and cost savings as motives. Some of these endogenous and exogenous factors were corroborated in this study.

Objective 2 was to consider the likelihood of Government support i.e. FITs accelerating PV uptake and to establish whether household PV uptake could lead to energy use efficiency.

Much of the answers to this objective were provided in Chapter 4, which centred solely on comparative PV, MGT and RET policies. From this analysis, the role of regulatory and fiscal incentives was obvious for PV adoption and diffusion, even in rich countries. The incentive aspect featured in methodology Chapter 5 and the fiscal part was addressed using a hypothesized discount applied to the PV price quote from EP Scheiba Germany presented in the questionnaire. To provide answers to the second part of objective 2, the review in Chapter 3 provided a background. Also, the interviews conducted following the design in Chapter 5 and detailed in Chapters 6 and 7 showed that post-PV, households engaged in more energy conservation like Keirstead (2007) reported. In this study the presence of a meter and efficiency limits of PV led to the energy management. The PV efficiency cycle in Chapter 8 was also used to demonstrate how the behavioural changes in PV households occur. Where a large number of households install and use PV it will thus lead to more efficient use of energy.

Objective 3 was to gain insight into the factors necessary for a successful of PV implementation policies.

Similar to objective 2, this was largely answered in Chapter 4. From the taxonomy of policies it became apparent that in most locations PV was supported using a number of mechanisms depending on policy goals and objectives (Mendonça et al, 2009; Jäger-Waldau et al, 2011). For most of the countries investigated, the goal was either to lower CO_2 emissions or for energy security or both. The presence or lack of incentive support impacted PV adoption and diffusion both directly and indirectly. For power supply which is traditionally the responsibility of the Nigerian Government, such incentives become all the more important. Also, given that PV power is low carbon and has positive externalities, the need for incentives becomes heightened. Clear, consistent, sustained support following meticulous planning leads to a successful PV implementation.

Objective 4 was to provide a knowledge-based evaluation of PV policy options in order to give the Nigerian government confidence to support private sector investments in PV.

The policy evaluation carried out in Chapter 4 shed light on some key policy options for unsubsidised markets like Nigeria. The literature reviewed in Chapter 3 also examined WTP in developing countries of Asia and Africa, as well as funding practices for green electricity. It was revealed that there were different forms of support including donor driven. For instance it was shown that Kenya made use of cash mode of payment at the early stages but that the government provided the right environment for the industry to thrive. From a Government support perspective, regulatory and political intervention in the form of import duty cuts, tax rebates, appropriate certification of dealers and installers was shown to be necessary. This led to the inclusion in the survey design (Chapter 5) of outright mode of payment and provision of credit facilities. The policy analysis also pointed to the use of policy combination or hybrid policy e.g. low-cost loans in combination with FITs or community systems. Since the FITs is not yet operational in Nigeria, discounts to reduce costs and community PV was suggested alongside ensuring importers, dealers and installers engage in fair business practices.

Objective 5 was to design a PV uptake adoption model to assist individuals and government with promoting urban residential PV for low, medium and high income households.

This was answered in Chapter 8. However, creating the model would not have been possible without the data collected through the surveys and the interviews in Chapter 5 that led to the results in Chapter 6 which was discussed in Chapter 7. The selected variables from the findings include power outages (levels of grid supply received), alternative sources (fossil and green power) including inverter use, electricity costs/kWh, household energy demand based on power audit estimate (Chapter 5), income, awareness, PV sizes for different household groups, communal PV, financing, environmental consciousness, energy conservation and education. However, power outage and cost were given the highest weight. Using these key findings and the LCOE calculations, it was possible to design this model in a way that not only the Nigerian Government and policymakers can use but also PV designers, SMEs, and households (low, medium and high income) can easily apply in their PV adoption decision-making.

9.3 Key findings and research output

As previously shown using the STEER factors, the major findings of this research are as follows:

- There exists an impressive degree of interest in PV electricity by households.
- The adopters found PV to be reliable and more secure than centrally supplied power and auto-generation.
- That PV resulted in energy cost savings for the adopting households.
- The finding that PV was a simple solution to generator use fuel fraud thus making for additional savings for adopters.
- It was revealed that Government monetary and regulatory support is needed.
- It was also found that more education (formal and informal) is necessary to increase awareness and change consumer perception of PV costs and efficiency.

9.4 Research output

1) The discovery that households adopting PV resulted in increased energy use efficiency, culminated in the development of the PV efficiency cycle in Chapter 8.
2) Specific findings obtained from the comparative policy analysis and the questionnaire and interview results, led to the design of the PV verified model for rapid diffusion detailed in Chapter 8.
3) In this same chapter, using LCOE calculations, PV was found to be cheaper and more cost-effective compared to grid supply and use of generators as cited by the adopters. This, together with the verified model, helped to reveal the attainment of grid parity[36] in Nigeria.

Therefore, there are 2 principal contributions of this study to scholarly knowledge:

1) It extends the stock and understanding of MGT adoption and diffusion theories from the perspective of urban households in unsubsidised markets and
2) It provides practical guidance for the design of PV support programmes for wider spread adoption and eventual diffusion.

9.5 Limitations of the study

A key limitation in the questionnaire administration and interviews was reaching households. The geographic distribution and traffic in Lagos presented huge challenges which added to research time. Also, the limited number of PV users resulted to the entire data collection process lasting close to 6 months. This led to delays but does not diminish the importance of the findings. For this reasons, future research of similar studies may want to consider using focus groups for data gathering.

9.6 Areas for future study

Further research that investigates the economic loss to inverter users, SME owners and large businesses from private power generators can be carried out. It will be useful to conduct a research that solely investigates this group using a large sample. Its purpose will be to quantify the losses arising, including where generator fuel fraud is suspected. Such a study, will help strengthen proposal to this group, that PV is a mechanical solution to generator use fuel fraud. The advantage for large businesses e.g. banks is

[36] This is the point where PV prices become competitive or equal conventional electricity prices.

that they are likely to have funds and roof/ground space requirements more than any other group. Finally, future research may want to investigate the most effective PV promotion policy for industry and commercial sectors and the most suitable financing options.

9.7 Summary and recommendations

The motivation for this study was to help provide the mechanisms to assist the Nigerian Government and energy consumers at the residential-scale in particular with bridging the gap between power supply and demand. It was also to show the socio-economic and environmental benefits of pursuing a low-carbon path in Nigeria. Through the combined research methods and field survey analysis, the potential and opportunities that PV presents was demonstrated.

Thus the key contribution of this study is to emphasize the benefits of PV. Encouraging and supporting PV use, represents taking a shorter route to achieving similar levels of comfort in dwellings to that of grid electricity. Having increasingly showed interest towards diversifying the power sector through policies like the REMP, it is time for the Nigerian Government to act. It is not beyond the bounds of possibility for the Nigerian Government to, at this stage of PV development, provide discounts and non-fiscal incentives. '*Light poverty'* is an injustice. As households and investors genuinely seek to coproduce power sustainably through self-help, the least that is expected is to create a secure platform through effective laws and regulation, which would serve to reduce risks and protect the investments of these innovators.

The topics explored in this study are used to provide evidence in support of the theory that PV uptake in urban Nigeria will lead to an improvement in power supply and demand, both at the disaggregated level of households and at the national level. Finally, it is hoped that this research changes the disposition of the Nigerian Government towards the evidence that is presented to act accordingly. The particularly relevant self-generating '*experiences*' gained by Nigerian households will be central to power stability and renewable power transition in Nigeria.

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Appendix A

Questionnaire Survey: Research ethics and confidentiality

Questionnaire Title: Energy supply for urban household use in Nigeria.

Description of Study

This research is carried out as part of a PhD study. In an effort to improve electricity supply for households through more sustainable independent power-generation, the research is aimed at investigating the constraints to the uptake of solar photovoltaic (PV) systems by urban households.

Purpose of Questionnaire

The purpose of this questionnaire is to gain a better understanding of the difficulties households face in their energy demand and also help identify major ways by which the uptake of solar home PV systems can be encouraged for better power supply.

Target Group

This questionnaire is mainly targeted at urban households in Lagos. This includes homeowners and people renting their dwellings. It is to be completed by the head of the household concerned.

Approval from the Ethics Committee

Ethical implication of study was considered and an approval was granted by the ethical committee according to the research ethics guidelines and procedures of the University

Confidentiality and Disclosure of Information

Any information provided by you will be used only for research purposes. All information will remain confidential and will be disclosed only with your permission. I would also like to assure you that under no circumstances will you be identified. Some of the information will be recorded and subsequently transcribed but no personal data will be given to any third party without your consent.

Your participation is highly appreciated.

If you have any questions you would like to discuss about the research, please contact me on the following address:

Correspondence Address: **Anthony Ugulu, PhD Research Student**, Heriot-Watt University, Energy, Geoscience, Infrastructure and Society, School of the Built Environment. Email: aiu30@hw.ac.uk.

If you also have any additional questions that you would like to discuss with my research supervisor, please contact Senior Lecturer **Dr Gillian Menzies**, Energy, Geoscience, Infrastructure and Society, School of the Built Environment, Heriot-Watt University. Email: g.f.menzies@hw.ac.uk.
Phone number: +44 131 451 4663.

QUESTIONNAIRE

Dear Respondent,

Energy supply for urban household use in Nigeria

As part of a research project at the Institute for Building and Urban Design, Heriot Watt University, Edinburgh UK, this survey is being conducted to investigate energy consumption by urban households in Nigeria.

This survey focuses on households in Lagos state. The aim of the survey is to understand the energy demand of households and how this can be matched with a more sustainable supply.

The survey is to be completed by the head of a household and should take approximately 25 minutes to complete. Please answer all the questions to the best of your ability. The results will only be used for a student's doctorate and the information you provide will remain anonymous and confidential. All responses will be analyzed in aggregate and no individual responses will be referenced or used in any way. In appreciation for your time, findings will be made available to participants upon request.

Thank you.

Introduction:

The Nigerian Government aims to improve electricity supply through renewable energy technologies and is considering encouraging increased use of solar home PV systems for electricity generation in dwellings.

Your answers to these questions will help better understand household energy consumption, so as to allow for effective support and design of sustainable electricity supply systems.

Information about you:

1. Gender Male ☐ Female ☐

2. Age

18-30yrs	
31-44yrs	
45-64yrs	
Over 65yrs	

3. How many people, including yourself live in your home?

2	
3	
4	
5	
6 or more	

4. Please indicate the ages of those in your household, including yourself?

Age (years)	No of households 1	2	3	4	4+
0-9					
10-17					
18-30					
31-44					
45-64					
Over 65					

Dwelling profile:

5. How many bedrooms are there in your home?

1	
2	
3	
4	
5	
6 or more	

6. Do you own your home?

Yes ☐ No ☐

7. Which of these best describes your dwelling situation? Please tick one:

Self-built	
Purchased	
Mortgage	
Renting	
Other (please specify)	

8. Which of these best describes your type of dwelling? Please tick one:

Duplex	
Bungalow	
Detached house	
Semi-detached	
Terraced house	
Flat (Apartments)	
Other (please specify)	

9. How old is your dwelling?

1-10 years	
11-15 years	
16-20 years	
20 years +	
Don’t know	

10. Using the scale below, how likely are you to move to another dwelling in the next 10 years?

Not at all likely	
Slightly likely	
Neutral	
Quite likely	
Extremely likely	

11. Which of the following bands best represent your approximate total household income per year?

Less than ₦1m	
₦1m-₦3m	
₦3m-₦5m	
₦5m-₦10m	
₦10m-₦20m	
Over ₦20m	

12. What is your level of education? (Highest qualification only).

Education	**Tick one**
Postgraduate	
Undergraduate	
Secondary or equivalent	
Primary	
Informal education	
No formal education	

13. Please indicate the Local Government Area you live in Lagos State?

Environmental Issues

Your answers to these questions will help understand your views on environmental issues.

14. Please indicate the extent to which you agree with the following statements:

a. Global warming is as a result of emissions from the use of fossil fuels such as coal, petrol and diesel

Strongly disagree	
Disagree	
Neutral	
Agree	
Strongly agree	

b. "Many of the claims about global warming and its impact on cities on low-lying coastlines are exaggerated."

Strongly disagree	
Disagree	
Neutral	
Agree	
Strongly agree	

c. "I am a well-informed individual in terms of global warming issues."

Strongly disagree	
Disagree	
Neutral	
Agree	
Strongly agree	

Household energy use

Your answers to these questions will help understand energy use efficiency awareness.

15. How often do you check your home electricity consumption? E.g. by going through your electricity bills in details.

Weekly/Biweekly	
Monthly	
Quarterly	
Twice a year	
Annually	
Very infrequently	
Not at all	

16. Have you adopted any energy saving measures in your home?

Yes ☐(Go to **Q17**) No☐ (Go to **Q18**)

17. What energy saving measures do you have in place? Please select all that apply.

Switching off electrical appliances when not in use	
Use of energy saving bulbs	
Switching off lights when not in use	
Purchase and use of low energy appliances	
Monitoring home energy use	
House designed to capture natural light	
House designed for natural passive air flow	
Washing machine always set to 30^o when doing laundry	
Other, (please specify)	

18. Which of the following do you or members of your household do? Please select all that apply.

Recycling	
Boiling or heating only the amount of water required	
Walking, cycling and the use of public transport	
None	
Other, (please specify)	

Electricity supply from PHCN

Your answers to these questions will help understand the level of power shortages households' experience.

19. Are you affected by power cuts where you live?

Yes ☐ No ☐

20. Overall, how satisfied are you with the level of electricity supply from PHCN?

Extremely satisfied	
Satisfied	
Neutral	
Dissatisfied	
Extremely dissatisfied	

The Nigerian Government subsidizes electricity prices to make it affordable, but this has partly contributed to the electricity shortage problems.

21. On average, how many hours of electricity do you get in a day?

22. Would you be willing to pay more for improved and more regular electricity supply from PHCN?

Yes ☐ (go to **Q23**) No ☐ (go to Q24**)**

23. How much more are you willing to pay?

Less than 10%	
10-25%	
25-50%	
50-75%	
More than 100%	

24. If you are not willing to pay more, please explain why in the box below?

Substitutes to PHCN supply

Your answers to these questions will help understand your alternatives to PHCN supply.

25. Which of the following alternatives for electricity shortages do you use in your home? Please select all that apply.

Candles	
Kerosene/Gas lamps	
Petrol generator	
Diesel generator	
Solar PV	
Micro wind turbine	
Other, (please specify)	

26. If you use a petrol or diesel generator or both in your home, on average, how much do you spend on fuel and maintenance of the generators in a month?

27. Which of the following images best represents your home generator?

Representative Image	**Tick all that apply**
	
	
	
	
None	

28. Fossil fuels can cause air and noise pollution. Which do you think affects you the most in your home through generator use?

Air pollution	
Noise pollution	
Don’t know	
None	

Solar PV use

Your answers to these questions will help understand the level of awareness of solar PV systems.

29. Have you heard of a solar PV system?

    Yes ☐ (Go to **Q30**) No ☐ (Go to **Q34**)

30. If yes, how?

    Please select all that apply.

Internet	
Seen on the roof of a building	
TV/Radio/Newspaper and Billboard Advertisement	
PV promotion campaigns	
Neighbours/ Word of mouth	
Other, (please specify)	

31. Do you have a solar home PV system?

    Yes ☐ No ☐

32. Do you have a friend or neighbour who has installed a solar PV system in their home?

    Yes ☐ No ☐

33. Please indicate the extent to which you agree with the following statements:

a. "A solar home PV system is reliable and efficient."

Please tick one.

Strongly disagree	
Disagree	
Neutral	
Agree	
Strongly agree	

b. "I would be willing to pay more for a solar home PV system if it guaranteed regular electricity."

Please tick one.

Strongly disagree	
Agree	
Neutral	
Agree	
Strongly agree	

Motives and Barriers

34. **A typical 5kWp solar home PV system can provide all the energy needs of a 3-member home, and up to 50% of the energy needs of a larger household. It is quiet in operation and does not require fuel to run. It will cost a total of between N4million-N5million to install, and the lifetime is around 30 years. Payback period depends on energy use within the household and PHCN electricity prices.**

    In how many years should a solar home PV system pay for itself in order that you decide to install it in your home?

10-12 years	
12-15 years	
15-17 years	
17-20 years	
20-25 years	
25-30 years	
Other, (please specify)	

35. **Kenyan and South African Governments support solar home PV systems by covering some of the cost of installation for households.**

If the Nigerian government does the same, what amount of subsidy will make you willing to install solar PV in your home?

25% towards total cost	
30% towards total cost	
40% towards total cost	
50% towards total cost	
60% towards total cost	
None	
Other, (please specify)	

36. Some Kenyan households use unaided self-help. Would you be willing to install a solar PV system in your home without any form of help or Government subsidy?

Yes ☐ No ☐

37. If you had access to loans for a solar PV system, would you consider this?

Yes ☐ No ☐

38. Please **rate** your most preferred form of financial aid towards a solar home PV system?

(Where 1 = least important; and 5 = most important).

Forms of aid	**Rating**
Tax credits	
Import duty cuts	
Government subsidies	
Bank loans	
VAT exemptions on PV equipments	

39. If PHCN offer to buy the surplus electricity generated by your home PV system, would you consider this?

Yes ☐ No ☐

40. Please **rate** the following reasons for wanting to install a solar home PV system.
(Where 1 = least important; 5 =most important).

Reasons	**Rating**
Environmental protection	
Power cuts	
Self-sufficiency/ independence from PHCN	
Love for modern technology	
Self-identity/ Prestige	
Comfort/Health and Wellbeing	

41. What do you consider the two most significant constraints to installing a solar PV in your home?

Please select only **two**.

Planning permission and regulation problems	
Financial constraints	
PV efficiency issues	
Fear of damage to home	
Payback period	
Lack of reliable installers	
Inadequate roof space	
Inconvenience and installation hassle	
House move and house resale value	

42. Using the scale below, please rank how you feel about the following statements related to solar home PV use.

Statement	Your opinion 1 = Disagree strongly; 3 = Neutral 5 = Strongly agree				
	1	2	3	4	5
Solar home PV is too expensive to buy and maintain					
PV is not efficient/Unreliable supply					
PV Installation can cause damage to home					
PV can increase house value					
PV is difficult to use					
It is hard to find trustworthy installers					
It has long investment payback period					
Inconvenience associated with installation					
PV will affect my home resale value					

43. What would provide the greatest motivation for you to install a solar home PV system?

Please select only **two**.

Reliable electricity supply	
Environmental protection	
Easy to use	
Self-reliance/Independence from PHCN	
Government support or other forms of financial aid	
Reduced PV cost	
Availability of trustworthy PV installers	

44. If you have a solar PV system in your home, in order to discuss your experience as a user, would you be willing to participate in a 30-minute face-to-face interview?

Yes ☐ No ☐ Not applicable ☐

45. If yes, please provide your details below stating a convenient time to call to arrange an interview.

Name...
Address...
....
Phone number......................................
Time..
Email...

Thank you for completing the survey!

Appendix B

A sample interview

This appendix contains the transcript of a discussion with F.I., one of the most interesting households surveyed. Mr F.I is a 52 year old Pharmacist. He lives with his wife in Festac 2 Lagos in a home that he rents with his pharmacy and supermarket less than a 10-minute walk away from his residence. The interview was made in his home on 20 November, 2013 at 6pm and the transcript begins after granting permission to record interview.

AU: I just wanted to ask how long you have been using your solar panels?

FI: I have been using it for a little over one year now.

AU: Do you know the capacity? I mean the size of the system?

FI: Yes. It’s a good size. I think it is about 7.5kVA.

AU: What is your major motive or reason for installing the solar panels?

FI: I installed the solar panels to reduce operating costs; because we spend a lot of money in purchasing fuel for running our generators. The high cost of a solar system is a one-time investment and the thing is that you can recover your investment costs. The money you save from fuel within a year, you can recover it. It is cheaper and it makes light always available for me. Although my system cannot power all my appliances, it is cheaper. If I have to power all my devices I will need to get more panels.

AU: Interesting. Thank you. Before you installed your solar panels, were you purchasing or using energy-saving appliances, for instance, lightbulbs?

FI: Yes I was. Energy-efficient bulbs are taking over from the filament-type bulbs. I already had the energy saving bulbs. Most people now use these energy saving bulbs these days.

AU: Do you think using solar panels have made you more aware of your energy use to the point where you start considering other low energy appliances?

FI: Of course, yes. I have become more conscious of my energy use. I would have changed my refrigerators to energy-saving ones but the cost is too much.

AU: Before getting your PV, I mean the solar panels, what percentage of your appliances would you say was energy efficient?

FI: Say about 30-40% of my appliances; mainly light bulbs.

AU: Can you think of any changes in your dwelling since getting a solar panel that might affect the total amount of energy use?

FI: The thing is that my staff members are not aware of energy use. Sometimes they do not know the difference between PHCN-supplied energy and solar generated power. They tend to want to use every appliance that is in the shop. But when I am around, if there is outage, I switch off some appliances to conserve power. Some members of my staff find it difficult to understand these things.

AU: Does your solar PV have a display meter?

FI: Yes. The inverter that came with the installation has a metre for me to know whether my battery is charging or if I am using the energy from the battery to supply. I try to adjust what I am using in order to conserve more power to use at night. Because you see the charging rate if it is decreasing, you know that you are using more than you are getting from the sun. But, if it is increasing, you know that you are using less than you are getting from the sun. With the meter, I know I am generating enough energy to power my equipment while at the same time charging the batteries.

AU: Where is the display meter located?

FI: It is on the inverter which is located inside the house, where you see the rate of charging and know that the battery is charging. If the charging is decreasing, you know that you are using more than you are getting, but if it is increasing, you know that you are using less than you are getting.

AU: Right, okay. How often do you check the meter?

FI: Not often, say once a day when I'm around.

AU: Considering the cost of purchase, how long do you think it will take for your system to pay back?

FI: I think in about one year and three months I will recover the cost of investment. Yes, because I actually bought second-hand batteries.

AU: Okay. Since you installed your system have you had any problems?

FI: Yes, there was a time I had problem with the inverter charge controller. The person that I called in to help me fix it, I didn't know that he didn't have the required knowledge. He did work on it but it was still not working effectively so I later got someone else. I was then asked to replace the charge controller. I sold off the old batteries because they were giving problems and got some new batteries. The new ones that I later got were not actually new. You know these guys that install the systems; they play a lot of tricks. That is why some people tell you that solar PV system doesn't work. The installers do not give them quality batteries. Those batteries from China are not good. Batteries from America and the western world are better. They are more expensive but they are better. Even the solar panels from China, they are not so good solar panels. They have good Chinese products but they really don't bring those products here. That's the problem. If you want to buy anything battery/panels, just try to buy those from the western world. Those ones can last up to seven years. There are some batteries that can last between twelve to fifteen years. Like those Chinese batteries that I bought, they changed the labels. The batteries are actually 150 watts; they now changed it to 200 watts. They play a lot of tricks. Also the solar chargers, some of them are better than the other ones. I am looking to buy some more new ones.

AU: Okay, I see. Would you recommend solar panels to people?

FI: Of course, I will recommend PV. I actually have it here, not only in my shop. Only that the problem I had last time with the charge controller affected the one I use here at home. The person I called initially who was not very knowledgeable installed it incorrectly and it has not been working. I am familiar with solar panel and I find it very convenient and comfortable to use so I will repair my system if I find a good technician. For instance, if it was working here, during the power outage, they would have been an automatic switch-over. Certain things in my house will not be on. I usually exclude things like air-conditioners from the inverter system because the starting power of air-conditioners and deep freezers can be very high. If you call a competent electrician to install the inverter for you and exclude things like air-conditioners. Because refrigerators and air-conditioners keep re-starting, they draw a lot of power from the batteries therefore shortening the life-span of the batteries.

The switch over system of the inverter means that both power from PHCN and the solar panel are channelled into the inverter. When there is power outage, the switch takes place and the only way we know is that there will be changes in the intensity of the light. The switch-over is a seamless connection. Solar PV system is cheap. It's like you are wasting money when you are using generators. Apart from the noise, the purchase of fuel products, you need to service the generators, you need to buy oil. The generator will go bad, you need to fix it. Solar inverters are very reliable. Like the ones I have the power surge cannot disturb any overload. They are very rugged.

AU: Right. Ok. Do you have any further thoughts on solar PV and how its use can be promoted?

FI: The thing is that Government subsidize the use of solar panels abroad and people generate power and sell to the national grid. Consumers supply excess to the national grid and buy from the grid when they generate insufficient quantities. If I have the opportunity to sell my surplus energy back to the grid, I will participate. I have spoken to my association chairman-The Association of Community Pharmacists on how our members can get it and start using it. You know the initial capital requirement is high so it's difficult for people to key in. But when people can acquire it and just pay gradually, even from the savings they make from not using fuel it becomes very easy for them to acquire it. I was very fortunate that my solar panels I got them from a neighbour who is a seller of PV systems and I was paying him gradually. But I have always known about inverters since the 2000s. The problem is more of financial constraints and level of awareness. Some people come around, they ask me and I explain to them but the cost of acquiring it is the problem. So they just prefer to continue using what they have and be spending maybe like ₦2000-3000 every day instead of putting in about ₦750,000 or thereabout. But you can go from one step to the other. You can first of all acquire your inverters and batteries without the panels then later you upgrade. If you have only inverter and batteries that means you need PHCN and generator to charge the batteries. But if you have solar panels, daylight can power the batteries and you may not need generator anymore all depending on the number of installed solar panels.

Awareness is very important. I knew that from the problems I was experiencing with my system, my batteries were not good enough. I kept telling my installer that they were not good and should be replaced and my installer was forced to change them. If I didn't know, I would have thought that that is what I am supposed to get from the system. I expected my brand new batteries to last at least 8 hours for me. The technicians play on the ignorance of consumers and give them sub-standard products. The installers they do a lot of things. They refurbish the batteries; they change many parts of the system they install to make much profit. Generally, German batteries and European batteries are very good and they can last for 10-15 years. If consumers get some form of financial support like the hire-purchase I was lucky to get, they will invest.

If government can encourage people by maybe letting them pay less tax or paying them for not polluting the environment. They do this abroad using the carbon trading. Since I am using PV systems, if there is any way I can benefit from doing this, it would serve to encourage people. We need something to make people see that their uptake of alternative energy sources are recognised and rewarded.

I tell you something. In my shop when I am away, I have been having the issue where my staff do not buy fuel for generator use but tell me that they did buy fuel. There might be '*light'* and they will say oh there was no '*light'*, that they bought fuel when they didn't buy fuel. So I have used my PV installation to cut off such dishonest practices. It is actually saving me a lot of money. They can tell you that they bought fuel and they used generator from morning to night when they didn't use it.

AU: Really? But you could ask from your neighbours if there was '*light*' during those times or not?

FI: Your mates are buying refinery and you are coming to check your fuel consumption….(laughs). People are beginning to buy energy saving bulbs and appliances. With the plan I told you about my Association, we are looking to help people buy PV and pay off gradually say within six months. People will start seeing the benefits from such support schemes.

AU: Interesting. Thank you very much. Please can I contact you at some point if I require you to answer a question or clarify something on this?

FI: Yes you can. It's not a problem.

AU: Thank you.

Appendix C

Sample NVivo Tag Cloud of the interviewed PV adopter's word frequency

actually adoption affect age also amount appliances aware batteries battery bulbs buy capacity challenges changes cheaper check come considering cost day display duration effect efficiency efficient energy every fuel generator get getting good grid high increased installation installed installing interview inverter know light like located long looking low made major metre might money monitor months motives much need now office often one panel panels payback people percentage power prior problem problems products purchase purchasing pv quality reasons recommend saving see since size solar suggestions supply sure system systems take things think time tv uptake use used user using years yes

Appendix D

SPSS output of Logistic Regression Results

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	183	91.5
	Missing Cases	17	8.5
	Total	200	100.0
Unselected Cases		0	.0
Total		200	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
No	0
Yes	1

Categorical Variables Codings

		Frequency	Parameter coding	
			(1)	(2)
Average monthly income recode	Low	80	1.000	.000
	Medium	72	.000	1.000
	High	31	.000	.000
Education recoded into 3	Secondary school	154	1.000	.000
	Undergraduate	22	.000	1.000
	Postgraduate	7	.000	.000

Block 0: Beginning Block

Classification Table[a,b]

	Observed		Predicted		
			Adopt PV		Percentage Correct
			No	Yes	
Step 0	Adopt PV	No	0	69	.0
		Yes	0	114	100.0
	Overall Percentage				62.3

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	.502	.153	10.836	1	.001	1.652

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	educrec	7.146	2	.028
		educrec(1)	1.639	1	.200
		educrec(2)	.019	1	.890
		increc1	7.450	2	.024
		increc1(1)	.761	1	.383
		increc1(2)	1.447	1	.229
		homowner	4.876	1	.027
		hrofsup	6.447	1	.011
		percost	2.309	1	.129
		subsrec	.777	1	.378
	Overall Statistics		32.294	8	.000

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	35.660	8	.000
	Block	35.660	8	.000
	Model	35.660	8	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	206.852[a]	.177	.241

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	5.071	8	.750

Contingency Table for Hosmer and Lemeshow Test

		Adopt PV = No		Adopt PV = Yes		
		Observed	Expected	Observed	Expected	Total
Step 1	1	15	14.055	4	4.945	19
	2	11	11.258	8	7.742	19
	3	12	9.798	6	8.202	18
	4	6	7.893	11	9.107	17
	5	8	7.240	10	10.760	18
	6	5	6.079	13	11.921	18
	7	3	4.790	15	13.210	18
	8	3	3.933	17	16.067	20
	9	4	2.498	14	15.502	18
	10	2	1.456	16	16.544	18

Classification Table[a]

	Observed		Predicted		
			Adopt PV		Percentage Correct
			No	Yes	
Step 1	Adopt PV (if reliable)	No	38	31	55.1
		Yes	18	96	84.2
	Overall Percentage				73.2

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	educrec			7.288	2	.026			
	educrec(1)	3.102	1.150	7.272	1	.007	22.250	2.334	212.119
	educrec(2)	3.073	1.226	6.277	1	.012	21.598	1.952	238.963
	increc1			3.287	2	.193			
	increc1(1)	-1.089	.606	3.224	1	.073	.337	.103	1.105
	increc1(2)	-.930	.589	2.496	1	.114	.394	.124	1.251
	homowner	.634	.390	2.637	1	.104	1.885	.877	4.051
	hrofsup	-.228	.061	14.125	1	.000	.796	.707	.897
	percost	.965	.469	4.233	1	.040	2.626	1.047	6.588
	subsrec	1.023	.521	3.857	1	.050	2.781	1.002	7.719
	Constant	-1.976	1.340	2.174	1	.140	.139		

a. Variable(s) entered on step 1: educrec, increc1, homowner, hrofsup, percost, subsrec.

```
             Step number: 1

             Observed Groups and Predicted Probabilities

      16 +                                                                                                    +
         I                                                                                                    I
         I                                                                                                    I
F        I                                                                                                    I
R     12 +                                                                                                    +
E        I                                           Y                                                        I
Q        I                                           Y                               Y                        I
U        I                                           Y                               Y                        I
E      8 +                                           Y                               Y                        +
N        I                                          YN                     Y  Y      Y           Y            I
C        I                                    Y Y   YN   Y         Y       Y  Y      Y      Y Y  Y  Y         I
Y        I                                    Y Y   YN   N     Y   Y   Y   Y  Y      Y      Y Y  Y  Y         I
       4 +                                    N N   NN   N    YY Y YY  Y   Y  Y      Y  Y  YY YY Y  YY        +
         I                 N                  N N   NN   N    YY N NY  N Y Y  Y Y    Y YY  YY YY Y  YY Y      I
         I                 N      Y        N  N N   NN   N   YNY N NY YN Y NY Y N  Y Y YYY YN YN Y YNY Y  Y   I
         I      NN    Y    N  N   N     YN NN N N YNNNYYNNN  YNNYN NYNYNNN NNYN NY Y N NYYYYN NN NYYNY Y YY   I
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYYY

          Predicted Probability is of Membership for Yes
          The Cut Value is .50
          Symbols: N - No
                   Y - Yes
          Each Symbol Represents 1 Case.
```

Graphical distribution of the frequency of predicted probabilities

Appendix E

Copy of 5kWp PV price quote - Travos Solar Company, Lagos 04/12/2013

Travos Solar Installation Quote for 5kWp PV

	Date 04/12/2013	
	Items	**Cost (₦)**
1)	16 Solar Panels	928,000
2)	Inverter	220,000
3)	Charge controller	80,000
4)	Battery (4)	200,000
5)	Installation materials	310,000
6)	Labour and Transport costs	200,000
Total		**₦1,938,000**

Appendix F

Copy of a 4kWp and 5kWp PV system-EMNI Sustainable Solar, Abuja Nigeria

EMNI Sustainable Solar Power System

INVOICE: EMNI/04/2016/ABJ **Date: 26 April, 2016**

Sellers Details	Buyers Details
NAME: EMNI Ssustainable Concepts (Nig) Ltd	**NAME:** Mr. Tony
ADDRESS : Mallam Shehu Plaza, 365, Awolowo way, Ground Floor, Jabi District, Abuja	**ADDRESS:** Lagos State
CONTACT: Emmanuel Okolo	**CONTACT PERSON:** Mr Sunny Okwudiashi

	Items	Quantity	Unit Price	Total AMOUNT
EMNI Sustainable Residential Solar System	1. Solar Panels (200w) Mono			
	2. Batteries Solar Gel (12v)	5 KVA/24v	₦1,680,000	₦1,680,000
	3. Charge Control Mppt (1pc)			
	4. Hybrid Inverter (1pc)	5 KVA/48v	₦1,930,000	₦1,930,000
	5. Battery Rack (1Set)			
	6. DC Circuit Breakers (Lots)	6.5 KVA/48v	₦2,480,000	₦2,480,000
	7. Cables & Other Accessories			
	Installation Cost ₦60,000 (Sixty Thousand Naira Only)			

Major Components' Sources: U.S.A, South Korea Hong Kong and Taiwan.

TERMS OF PAYMENT

- 70% down payment to be paid into the company's bank account as initial deposit, Balance of 30 % upon completion & commissioning of system.

Account Name: EMNI Sustainable Concepts Nig Ltd
Account Number: 0172727915
Bank / Swift Code: GTBank Plc / GTBINGLA
Sort Code: 05803215

NOTE: EACH SYSTEM IS SOLD BASE ON THE CURRENT EXCHANGE RATE @₦350/1$, INSTALLATION SPACE FOR MOUNTING PV MODULES AND OTHER SYSTEM COMPONENTS IS THE RESPONSIBILITY OF THE BUYER

Address: Mallam Shehu Plaza, Ground Floor, 365 Awolowo Way Jabi District, F.C.T Abuja Nig.
Tel: 08038340916, 08026037759 Email: emni.sustainable@gmail.com

Appendix G

Copy of PV quote (capital costs) for a 5kWp module supplied from Lagos

Call: 07080093799

ARTHUR ENERGY TECHNOLOGY LTD.

(De Solar People)

Solar Energy, Backups, Ups, CCTV, Fire Alarm Systems,
Bio-Gas, Wind Energy & Security Systems Etc.

HEAD OFFICE: 73, Okota Road Opp Godmon Estate Ago Okota Isolo Lagos.
Tel: 07032862249, 07025803611, 08033428078. E-mail: aarthurenergy@yahoo.com

MEMO

From: To: Date: 27/4/2016

Quotation for 5KWP OR 6.2KVA Solar panel System

ITEMS	Cost
1. 16 Solar panels PV (200W)	₦880,000
2. Inverter (5KWP)	₦250,000
3. Charge Controller (48V/60AMP)	₦50,000
4. Batteries x4 (200AH)	₦300,000
5. Installation materials Includes:	₦80,000
* Cable	
* Connectors	
* Switches	
6. Labour	₦100,000
7. Transportation	₦50,000
TOTAL COST	₦1710000

NOTE:
The pv cell module is mono cast (all made of silicons)

Appendix H

RETScreen software output used to estimate proposed PV yield for Lagos Nigeria

Natural Resources Canada | Ressources naturelles Canada | Canada

RETScreen® International
www.retscreen.net

Clean Energy Project Analysis Software

Project information

See project database

Project name	Residential PV Project
Project location	Lagos Nigeria
Prepared for	Various Stakeholders
Prepared by	Anthony Ugulu
Project type	Power
Technology	Photovoltaic
Grid type	Off-grid
Analysis type	Method 1
Heating value reference	Higher heating value (HHV)
Show settings	☑
Language - Langue	English - Anglais
User manual	English - Anglais
Currency	£
Units	Metric units

Site reference conditions

Select climate data location

Climate data location	Lagos
Show data	☑

	Unit	Climate data location	Project location
Latitude	°N	6.5	6.5
Longitude	°E	3.5	3.5
Elevation	m	32	32
Heating design temperature	°C	22.4	
Cooling design temperature	°C	29.0	
Earth temperature amplitude	°C	5.2	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		26.2	71.8%	5.28	100.2	3.3	27.8	0	501
February		26.6	74.8%	5.49	100.2	3.4	28.4	0	463
March		26.5	81.9%	5.46	100.1	3.2	28.2	0	511
April		26.6	83.5%	5.21	100.1	2.8	28.2	0	497
May		26.5	83.9%	4.76	100.3	2.4	28.1	0	511
June		25.7	84.2%	4.04	100.5	2.5	27.0	0	472
July		24.8	83.6%	3.95	100.5	2.9	25.7	0	459
August		24.5	83.8%	3.98	100.6	3.1	25.2	0	449
September		24.8	85.1%	4.09	100.4	2.8	25.8	0	445
October		25.2	85.4%	4.56	100.3	2.2	26.5	0	472
November		25.7	82.6%	4.95	100.3	2.4	27.2	0	470
December		26.0	75.5%	5.17	100.2	2.9	27.4	0	495
Annual		25.7	81.4%	4.74	100.3	2.8	27.1	0	5,745
Measured at	m					10.0	0.0		

NASA UNEP GEF reeep

Complete Energy Model sheet

RETScreen4 2013-08-27 © Minister of Natural Resources Canada 1997-2013 NRCan/CanmetENERGY

Appendix I

5kWp PV Dimensions -EMNI Sustainable Solar Abuja, Nigeria

Firstly,

1. One unit area size of 200w is 1482 x 992 x 35mm.   Weight 16.8kgs
2. One unit area size of 250w is 1665 x 991 x 50mm.   Weight 19.8kgs
3. One unit area size of 280w is 1956 x 992 x 50mm.   Weight 27kgs

Secondly**,**

If we are using 200w Mono PV total it is 18pcs

If we are using 250w Mono PV total it is 16pcs

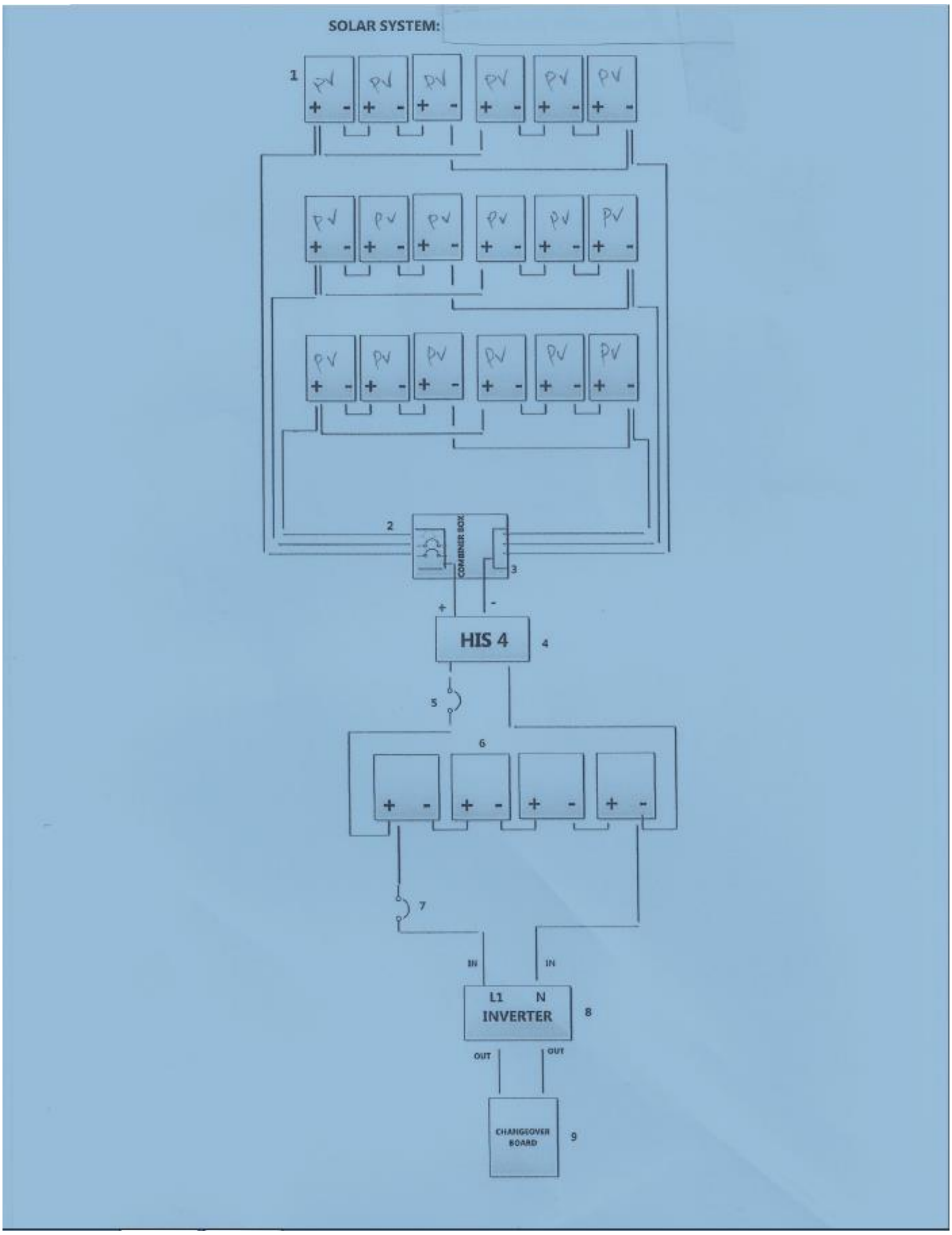
If we are using 280w Mono PV total it is 15pcs

They will have different system design to achieve 48volt.

Lastly, we need a total estimated size of 5x7 (Meter square) or 7x6 (Meter square).

Appendix J

Schematic drawing of the 5kVA PV system



Appendix K

Schematic drawing key of the 5kVA PV- EMNI Sustainable Solar, Abuja Nigeria

LEGEND- 5KVA SOLAR SYSTEM

1. PV ARRAY
2. 15AMPS CIRCUIT BREAKER (1 X 3)
3. COMBINER / FUSE BOX
4. SOLAR CHARGE CONTROLLER MPPT
5. 60 AMPS CIRCUIT BREAKER
6. BATTERY BANK
7. INVERTER SYSTEM
8. CHANGE-OVER BOX

CABLE RATING

1. PV ARRAY >COMBINER BOX:	4MM^2 COPPER WIRE
2. COMBINER BOX > CHARGE CONTROLLER	16MM^2 COPPER WIRE
3. CHARGE CONTROLLER > BATTERIES	16MM^2 COPPER WIRE
4. BATTERY BANK > INVERTER	16MM^2 COPPER WIRE
5. INVERTER > CHANGE-OVER BOX	10MM^2 COPPER WIRE

IMPORTANT NOTE:

WIRE RUNS (VERTICAL/HORIZONTAL) BETWEEN:

COMBINER BOX, CHARGE CONTROLLER, BATTERY BANK, INVERTER AND CHANGE-OVER MUST NOT BE MORE THAN 1.2-1.5 METERS OR 4-5 FEET APART.

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